5 Nutrients and Pathogens

Driftwood Beach on Blakely Island in San Juan County. | *Jim Johannessen*

1. Overview

Water quality is a primary factor affecting the health of marine and freshwater species in the Puget Sound region. As Washington's population grows and urbanization of the Puget Sound area continues, freshwater and marine ecosystems are under rising pressure from human activities that increase nutrient and pathogen pollution. Inputs of nutrients and pathogens affect ecosystem functions, the health and habitat of aquatic species, including economically important species (such as salmon and shellfish), and human health.

Nutrients consist of a variety of natural and synthetic substances that stimulate plant growth and enrich aquatic ecosystems. As a general rule, phosphorus tends to be the limiting nutrient in freshwater systems, and nitrogen tends to be the limiting nutrient in marine systems. This means that increased loadings of these nutrients can have significant effects on the character and condition of these respective systems.

Human activities have had a profound effect on the cycling of nutrients worldwide and nutrient pollution in the Puget Sound Basin. Nutrient availability in Puget Sound involves inputs from natural and human sources, such as upwelling and inflow of oceanic waters, flows from rivers and streams, stormwater runoff carrying fertilizers and other materials, discharges from sewage treatment plants, atmospheric deposition, and numerous other sources. It also involves uptake by phytoplankton and other aquatic vegetation and export to oceanic waters. Monitoring of nutrients is critical for assessing and understanding both short- and long-term changes in water quality and their effects on the Puget Sound marine ecosystem. Increased nutrient loading can dramatically change the structure and function of freshwater and marine ecosystems by altering biogeochemical cycles and producing cascading effects throughout the ecosystem and food web, such as prolonged algae blooms, depressed oxygen levels, fish kills and losses of aquatic vegetation. Eutrophication, as these nutrient-driven changes are known, is one the most important challenges facing Puget Sound and coastal ecosystems worldwide.

Pathogen pollution is an equally significant water quality problem in the Puget Sound Basin. Pathogens are disease-causing microorganisms that include a variety of protozoa, bacteria, and viruses. Some pathogens occur naturally in the marine environment (e.g., *Vibrio parahaemolyticus*). Most, however, are carried by host organisms and are associated with human and animals feces from such sources as onsite sewage systems and municipal sewage treatment plants, stormwater runoff, and boat waste. Pathogen pollution causes a range of environmental, human health, and economic impacts that include the contamination of shellfish beds, recreational waters and beaches, drinking water supplies, and other water-related resources. Pathogens also disrupt ecosystem functions and affect populations of freshwater, marine, and terrestrial species.

Increases in development around Puget Sound have prompted many investigations into the sources, loadings, pathways, and effects of nutrient and pathogen pollution. This information is needed to better understand the nature and scope of the problems and to inform management plans and efforts to prevent and control the pollution sources.

Key findings reported in this chapter include:

Fresh Water

- In Ecology's 2004 Water Quality Assessment, 58 freshwater sites were identified with **dissolved oxygen** problems in Puget Sound because of excessive nutrients (phosphorus and nitrogen) in the streams. Nutrients sources include drainage from agricultural, forestry, and residential activities and other sources.
- Twenty-five of 38 freshwater stations were scored "Good" according to the **total nitrogen** Water Quality Index. Ten stations scored "Fair." Three stations (in Hood Canal and on the Deschutes River near Olympia) scored "Poor."
- In 2005, freshwater stations were nearly equally divided between "Good" and "Fair" for **phosphorus** and were stable in water years 2000 through 2005.
- The WQI for **fecal coliform** rated "Good" at 28 of 38 freshwater streams for fecal pollution. The remainders were "Fair." Fecal conditions appear to be stable since 2000.

Marine Waters

- Hood Canal, Budd Inlet, Penn Cove, Saratoga Passage, and Possession Sound are locations of highest concern, based on Ecology's **index of water quality** for Puget Sound.
- Stations in Hood Canal, Penn Cove, Possession Sound, and Saratoga Passage had very high sensitivity to **eutrophication,** suggesting that these locations are at greatest risk for further declines in water quality due to human additions of nutrients.
- The most recent Water Quality Assessment lists 76 water bodies in Puget Sound with **fecal coliform** problems. However, fecal coliform data collected at marine ambient stations suggest a general decline in fecal coliform contamination from 2001 through 2005. The highest levels of fecal contamination occurred in Budd Inlet, Commencement Bay, Elliott Bay, and near West Point (north of Elliott Bay), Possession Sound, and Port Angeles harbor.

- DOH determined that 31 of 98 shellfish growing areas in Puget Sound experienced significant **fecal pollution** in 2005. Those with the greatest impact were Drayton Harbor, Dungeness Bay, and Henderson Inlet. Samish Bay and Burley Lagoon show no evidence of change in fecal pollution since 2002.
- Between 1995 and 2005, over 12,500 acres of **shellfish growing areas** were upgraded and 5,000 acres were downgraded, for a net increase of 8,500 acres. As a result of Kitsap County's Pollution Identification and Correction Program, parts of four shellfish harvest areas have been cleaned up and reopened for harvest; Burley Lagoon, Cedar Cove (part of Port Gamble), Illahee State Park, and Dyes Inlet.
- Twenty percent of 428 recreational beaches in 12 Puget Sound counties are threatened by **fecal pollution**. Five percent of these beaches are closed because of **biotoxins**. Within King County, trends at 21 recreational beaches indicate that fecal pollution has declined since 1997. Ecology's Beach Environmental Assessment, Communication and Health (BEACH) Program indicates that central Sound beaches typically have the highest measured bacterial pollution, most notably in Dyes and Sinclair Inlets.
- Eighteen of 29 **paralytic shellfish poisoning** (PSP) sampling sites (62 percent) had at least some PSP impact in 2005. Burley Lagoon ranked highest in PSP impact in 2005. The year 2003 appeared to be lowest in PSP activity throughout Puget Sound.
- In 2003, a short-lived ***Pseudo-nitzschia*** bloom occurred at Fort Flagler near Port Townsend. Mussels from the sentinel monitoring cage contained domoic acid slightly above the U.S. Food and Drug Administration's (FDA's) action level, and DOH closed the area to shellfish harvest. In October 2005, *Pseudo-nitzschia* blooms occurred at four places in north Puget Sound (Sequim Bay, Port Townsend, Holmes Harbor, and Penn Cove). Several shellfish species were affected. All four areas were closed to shellfish harvest.

2. Nutrient and Pathogen Monitoring in Puget Sound

Nutrients and pathogens are monitored at freshwater and marine sites by state agencies, local and tribal governments, and other organizations. The findings reported in this chapter come primarily from Ecology, DOH, and selected local governments.

With nutrients, water quality data is collected for different forms of phosphorus and nitrogen (e.g., ammonium and dissolved inorganic nitrogen) and combined with other information (e.g., marine water circulation and stratification) to provide a more complete picture of the effects in the receiving waters. Because of the difficulty and expense associated with the direct detection of pathogens in freshwater and marine environments, fecal coliform and enterococci bacteria are monitored as indicator organisms or surrogates that signal the possible presence of feces and waterborne pathogens. PSAMP scientists have developed a number of indices to consolidate and represent complicated data sets and, if possible, findings are presented both in terms of status (most recent conditions) and trends (changes over time).

State and local agencies use different monitoring strategies to meet their management goals. For example, Ecology is responsible for ensuring that water quality meets standards established by the federal Clean Water Act. Their monitoring programs are designed to assess the status of waters and to detect long-term changes from both natural and human causes using a range of physical, biological, and chemical parameters in fresh waters and marine waters in both urban and rural areas. Their data reported in this chapter are mainly from ambient monitoring conducted under PSAMP and recreational beach monitoring.

DOH's monitoring program is designed to classify shellfish growing areas under the National Shellfish Sanitation Program and to protect shellfish consumers from illness caused by pathogens and biotoxins. DOH uses water quality data from multiple sampling stations within each growing area, shoreline surveys, and other information to classify the different growing areas. Despite the narrower focus of the DOH program, the results have been adapted by PSAMP to measure water quality conditions and trends in the Sound.

Local and tribal governments and other organizations also monitor nutrients and pathogens in coordination or, in some instances, under contract with the state agencies to gauge conditions and trends and to guide shorter-term management actions. Results from a few of these local programs are included in this chapter to provide a more complete picture of the issues.

3. Impacts of Nutrients and Pathogens

a. Nutrients

Nutrients come from a variety of human activities and pollution sources, ranging from fossil fuel combustion to sewage discharges to forest practices, and they reach the receiving waters along a number of pathways (direct discharges, surface runoff, groundwater flow, and air deposition). There are also natural sources of nutrients that include the upwelling of coastal waters and runoff from the region's heavily vegetated landscapes, transporting large amounts of biomass to the waters of Puget Sound.

The effect of human activity on the global cycling of nitrogen in recent decades has been immense, and the rate of change in the pattern of use has been extremely rapid. One of the consequences associated with these changes has been the dramatic increase in nitrogen loadings to estuaries and coastal waters. So profound are these changes and loadings that some scientists contend that nutrients are now the largest pollution problem in the country's estuarine and coastal waters. The problem is likely to continue to worsen globally in concert with the expanding use of fossil fuels and inorganic fertilizers (National Research Council 2000, Howarth et al. 2002, 2000).

Under the right conditions, nitrogen inputs to marine waters can fuel algal blooms which, in turn, can reduce oxygen levels and harm marine life when the phytoplankton die back and decay in the lower water column. Sustained loadings of nitrogen and other organic matter can enrich and alter the marine ecosystem in many other ways. The direct and indirect effects of eutrophication are numerous and interconnected and range from reduced oxygen levels and biological diversity to altered food webs (Rabalais 2002, Diaz 2001, Cloern 2001, National Research Council 2000). The more enclosed areas of Puget Sound, including Hood Canal and the South Puget Sound and Whidbey basins, are vulnerable to eutrophication, due to slow flushing rates, limited stratification, and a number of other factors.

b. Pathogens

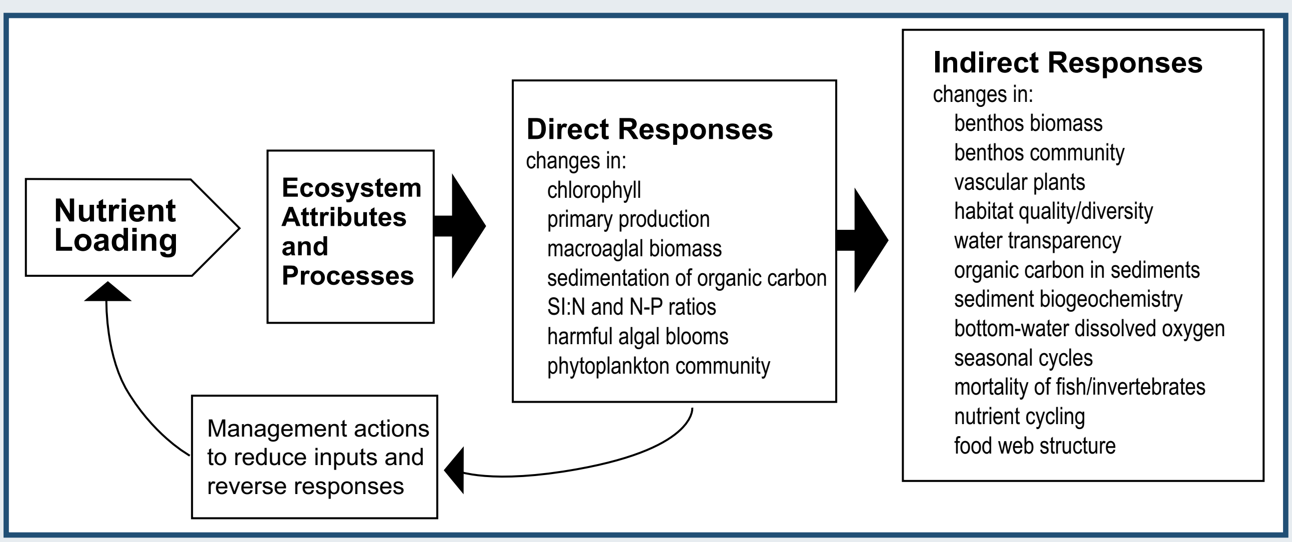
Pathogen pollution is a significant public health problem that also carries with it notable social and economic consequences. Pathogens are disease-causing microorganisms that include a variety of viruses, bacteria, and protozoans, most of which originate in the digestive tracts of humans and animals. Most waterborne pathogens make their way to the broader environment from such sources as sewage treatment systems, combined sewer overflows, stormwater runoff, and domestic animal and wildlife wastes. Pathogen pollution contaminates and affects the beneficial use of shellfish growing areas, recreational beaches, drinking water supplies, and other water resources. A leading disease risk to shellfish consumers are enteric viruses, especially a subgroup known as noroviruses that are frequently implicated in shellfish-related illnesses. Risks associated with swimming and other primary contact recreation include respiratory, ear, eye, and skin infections, gastrointestinal diseases, and other more serious conditions, such as meningitis and hepatitis.

Focus Study

Conceptual Model of Coastal Eutrophication

In his review of conceptual models of coastal eutrophication, James Cloern (2001) describes the evolution of these issues and explains several fundamental differences in the responses of freshwater and coastal ecosystems to nutrient enrichment. He describes coastal eutrophication as a "myriad of biogeochemical and ecological responses to human fertilization of ecosystems at the land-sea interface" and offers the flow chart below to help explain the cascading effects associated with coastal eutrophication.

All estuarine and coastal ecosystems have unique attributes that determine their sensitivity to eutrophication, and a number of management strategies can be used to mitigate and reverse the effects of pollution. Cloern also lists several challenges to the scientific community on the topic, including the need to develop nutrient budgets for different systems, to develop better indices to measure sensitivity to nutrient inputs, and to devise innovative ways to synthesize information from multiple sources to guide management plans.



Other pathogens occur naturally in the marine environment. Most notable among these in the waters of the Pacific Northwest is *Vibrio parahaemolyticus*, the most common cause of seafood-associated bacterial gastroenteritis in the U.S. Disease outbreaks associated with *V. parahaemolyticus* are most common in late summer months, when intertidal shellfish waters become warmer. Areas of Hood Canal and south Puget Sound are most susceptible to these conditions.

Biotoxins also present serious public health risks and can contaminate shellfish growing areas, leading to closures. Biotoxins are poisons produced in certain species of algae that, when they proliferate, are referred to as harmful algal blooms. The most common of these in Puget Sound is paralytic shellfish poison (PSP), which is produced by the phytoplankton *Alexandrium catenella* and can cause sporadic but widespread closures in Puget Sound. Common on the outer coast but only recently detected at a few sites in north Puget Sound is another biotoxin called domoic acid, the cause of amnesic shellfish poison (ASP), which is produced by the dinoflagellate *Pseudo-nitzschia*. First detected on Washington's Pacific Ocean coast in the in the early 1990s, domoic acid has resulted in lengthy closures of the coastal razor clam fishery. If organisms containing domoic acid were to move further into Puget Sound, the economic and public health implications could be dramatic.

Pathogens and biotoxins also pose serious risks to the health of marine wildlife. Coastal runoff containing the protozoan, *Toxoplasma gondii*, which is found in cat feces and is infectious to humans, has caused extensive infection and mortality in southern sea otter populations along the California coast (Jones et al. 2003, Miller et al. 2002, Gaydos et al. 2004) identified over 40 potential infectious diseases and listed morbilliviruses and herpesviruses as the highest infectious disease risks to the southern resident orca population of Puget Sound. Marine distemper viruses, such as phocine distemper virus or cetacean morbillivirus, have caused large die-offs of seals and whales in some parts of the world (Osterhaus et al.1995) but have not been documented in Puget Sound. Canine distemper virus has been transmitted from dogs to seals and has caused large-scale die-offs in Antarctica, Lake Baikal, the Caspian Sea, and other areas (Kennedy et al. 2000, Kennedy 1998). Having never been exposed to distemper viruses, harbor seals in Puget Sound would be very susceptible to infection if a canine distemper virus were to cross from domestic dogs to seals. Other protozoa such as *Cryptosporidium* and *Giardia*, which have long been thought of as terrestrial and freshwater pathogens, are also emerging as marine wildlife pathogens. Outbreaks of biotoxins have been implicated in the mortality of sea birds, sea lions, sea otters, cetaceans, and other wildlife on the West Coast (Lowenstine 2004, Trainer 2002). Additional research is needed to more fully understand the effects of these and other pathogens and toxins on the food web and the health of marine wildlife.

4. Fresh Water

Water quality characteristics of freshwater inputs are important controlling factors on the Puget Sound marine environment. As part of PSAMP, Ecology monitors 12 water quality parameters on a monthly basis at 24 long-term and 10 to 15 rotating river and stream sampling stations in Puget Sound. Ecology initiated its freshwater sampling program in 1970. These 12 parameters include nutrients (total nitrogen, ammonia, nitrate plus nitrite, total phosphorus, and orthophosphorus), pathogens (fecal coliform bacteria), temperature, DO, pH, conductivity, total suspended solids, and turbidity (Hallock et al. 2004). Ecology also monitors biological conditions (benthic invertebrates) and the spread of invasive, non-native aquatic plant species.

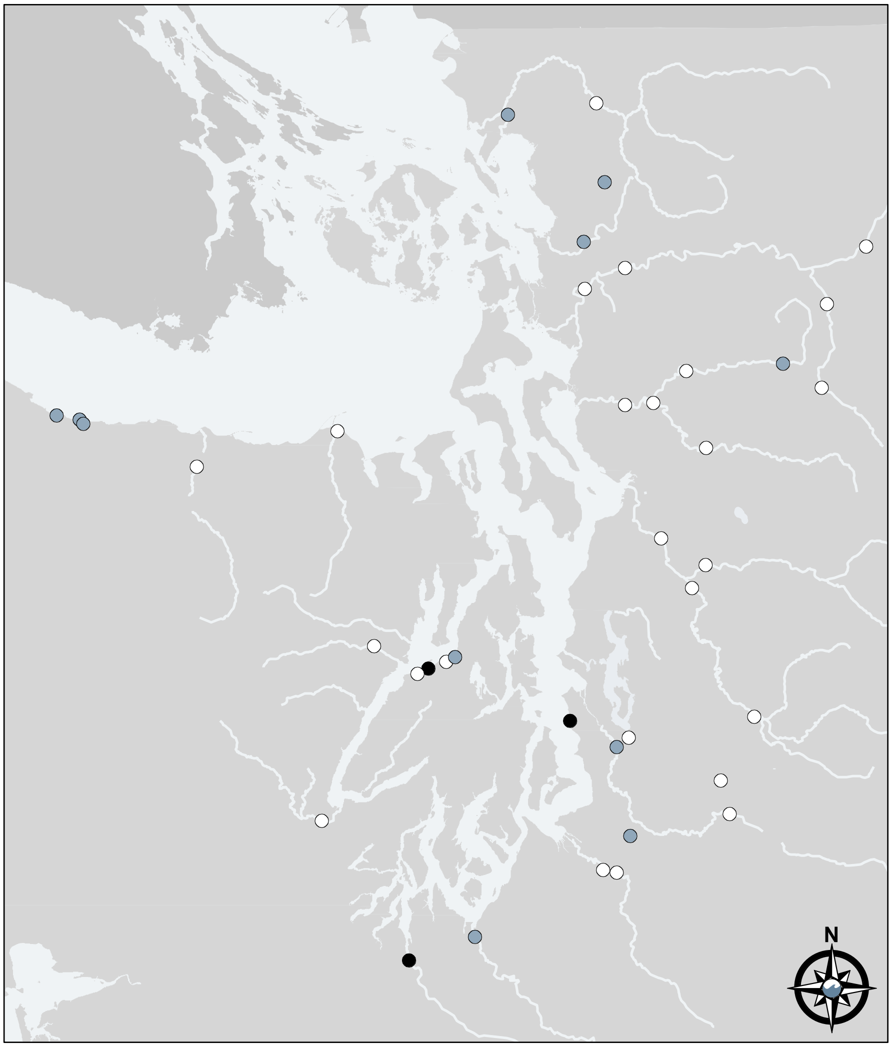


Figure 5-1. Ecology's freshwater core ambient monitoring stations and WQI scores for total nitrogen, 2000-2005. Fifty-six percent of the monitoring stations demonstrated good water quality, with low concentrations of nitrogen; 36 percent of the stations demonstrated fair water quality; and eight percent of the stations demonstrated poor water quality, as measured by high nitrogen concentrations.
(Source: Ecology)

● Poor
● Fair
○ Good

a. Nutrients

The State regularly assesses the condition of the state's water bodies. In the 2005 Water Quality Assessment, lack of oxygen was identified as a concern at six freshwater locations in the Puget Sound region. Other locations were deemed to be waters of concern for other indicators. One score of the Water Quality Index (WQI) assesses the nutrient status of rivers and streams based on concentrations of total nitrogen and phosphorus (Hallock et al. 2001). When concentrations of nitrogen and phosphorus are elevated significantly over background levels, this indicates a likely pollution problem. Common sources include: runoff from agricultural or residential areas where fertilizers are used; discharges from wastewater treatment plants or subsurface flows from shoreline onsite sewage systems; or runoff and sedimentation from logging practices.

Status and Trends

Figure 5-1 shows the total nitrogen WQI for sampling stations within the Puget Sound Basin based on 2000-2005 data. The results indicate good conditions at 22 of 39 freshwater stations. The remaining stations are in fair (14 stations) and poor (three stations) conditions. The stations with poor conditions were located in central Puget Sound, Hood Canal, and south Puget Sound.

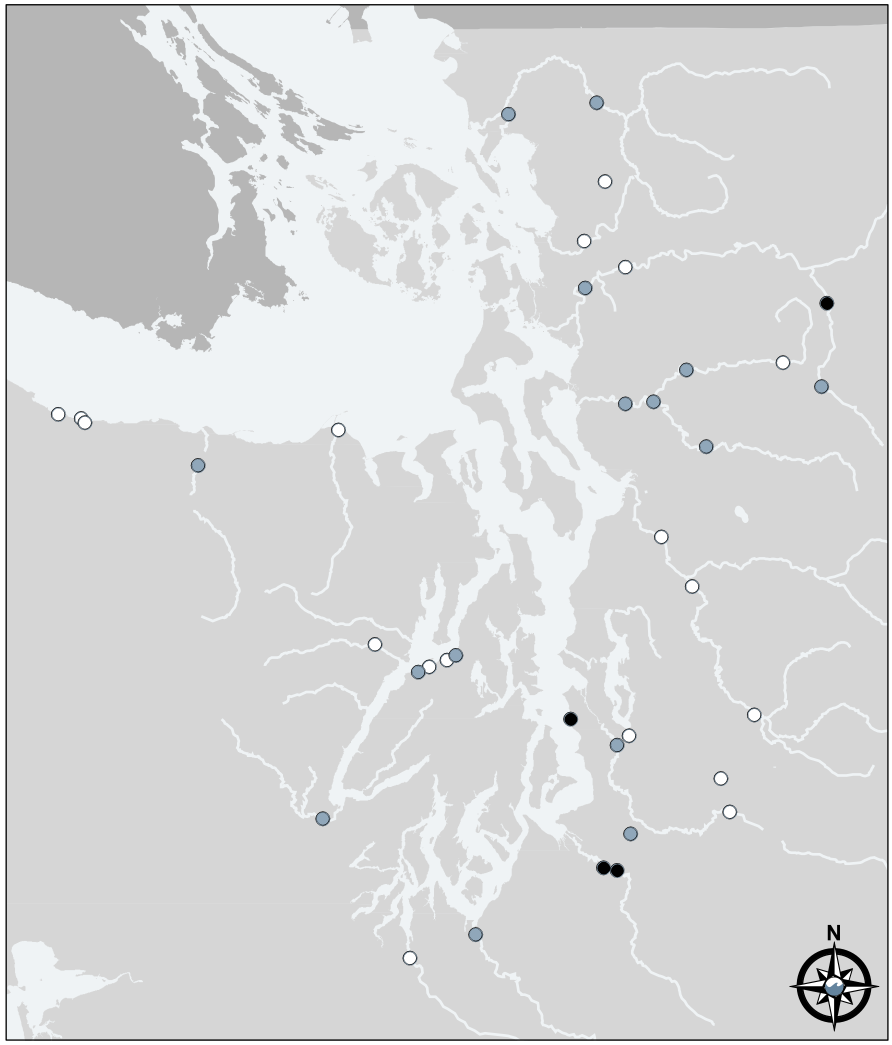


Figure 5-2: Freshwater quality for phosphorus in Puget Sound, 2000-2005. Freshwater long-term and rotating ambient monitoring stations and WQI scores for total phosphorus. Fifty-one percent of the monitoring stations demonstrated good WQI scores or low levels of total phosphorus, 36 percent of the stations demonstrated fair water quality, and 13 percent had poor water quality, as measured by high phosphorus levels.

(Source: Ecology)

- Poor
- Fair
- Good

Results for the total phosphorus WQI (Figure 5-2) show a different pattern than the nitrogen WQI. Five stations were rated poor for high phosphorus concentrations, 14 stations were rated as fair, and the remaining 20 stations were rated as good. The stations with the highest levels of phosphorus included Fauntleroy Creek (a small creek in West Seattle), the lower mainstem of the Sauk River, the White River, and two stations on the lower Puyallup River.

b. Fecal Bacteria

Fecal coliform bacteria are used as indicators of the potential presence of water-borne pathogens that are associated with human and animal wastes. The WQI for fecal coliform bacteria showed good conditions at most freshwater stations in the Puget Sound Basin.

Status and Trends

Freshwater long-term and rotating ambient monitoring stations and WQI scores for total fecal coliform for 2005 data are provided in Figure 5-3. The majority of stations (29 of 39) demonstrated good conditions and the remaining stations were rated fair.

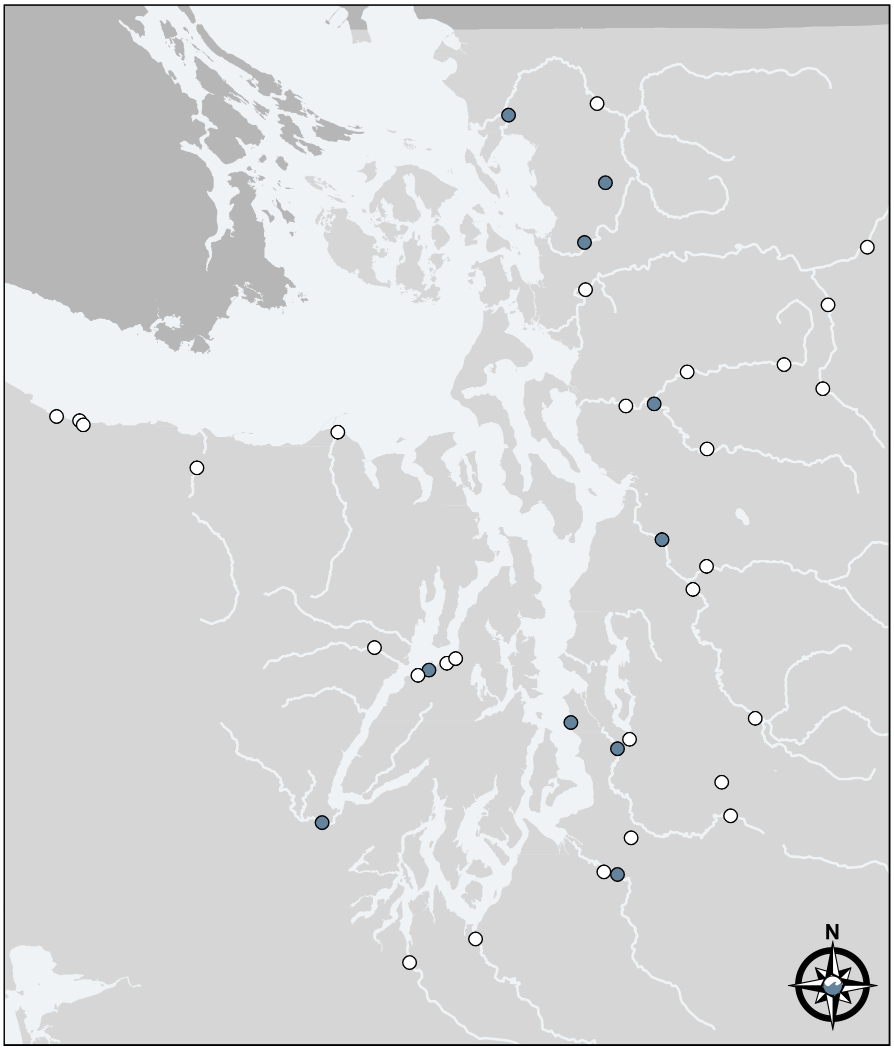


Figure 5-3. Freshwater quality for fecal coliform in Puget Sound, 2005. Ecology freshwater long-term and rotating ambient monitoring stations and WQI scores for fecal coliform based. Seventy-four percent of the monitoring stations demonstrated good conditions for fecal coliform, while 26 percent demonstrated fair conditions for fecal coliform. None of the stations demonstrated poor ratings for fecal coliform.
(Source: Ecology)

- Poor
- Fair
- Good

5. Marine Water

a. Water Quality Status

Ecology monitors marine water quality at long-term stations located throughout Puget Sound and in the coastal estuaries of Grays Harbor and Willapa Bay. In addition, the King County Department of Natural Resources and Parks conducts similar monitoring at a series of stations located in the Central Puget Sound Basin as part of PSAMP. Water quality variables measured by these programs include temperature, conductivity, salinity, density, DO, light transmission, nutrients (nitrate, nitrite, phosphate, silicate, and ammonia), and fecal coliform bacteria concentrations. The following section includes monitoring results for nutrients and fecal coliform bacteria and an index of sensitivity to eutrophication for locations monitored from 2001 through 2005.

Status and Trends

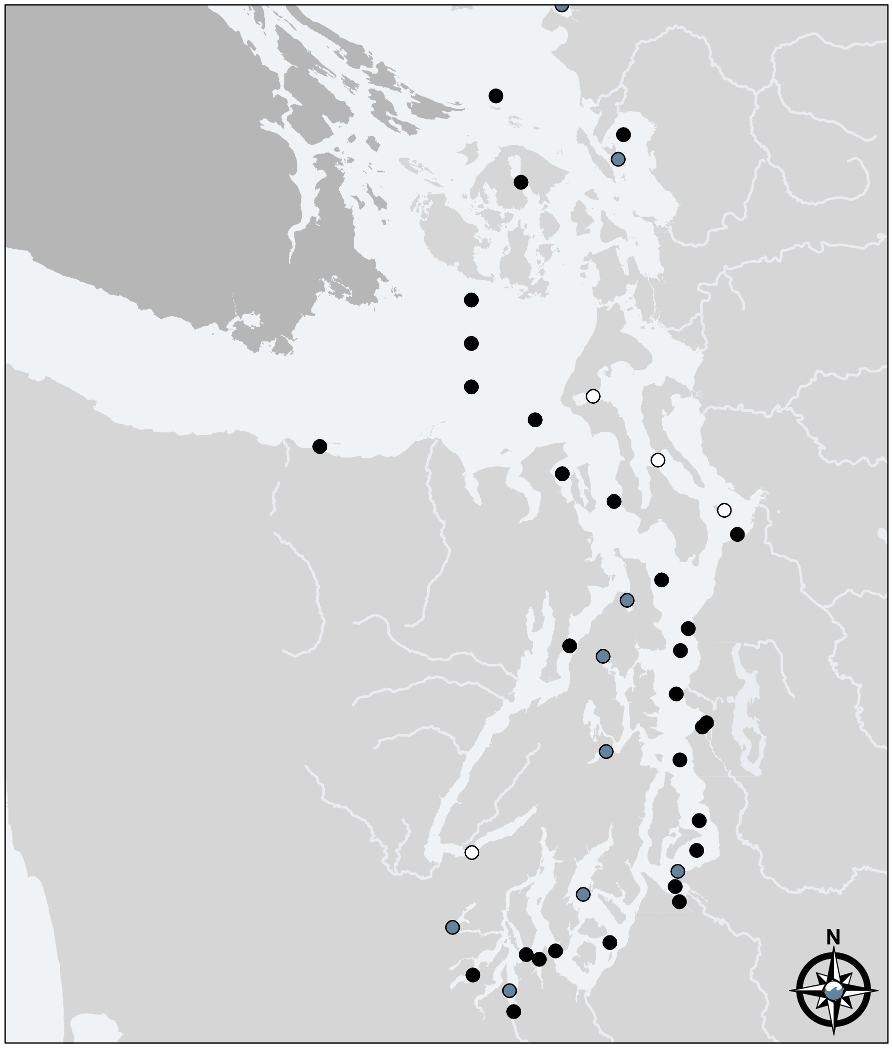
In marine ecosystems, nitrogen is usually the limiting nutrient for phytoplankton growth, so dissolved inorganic nitrogen (DIN), which includes nitrate, nitrite, and ammonium, is used as an indicator of nutrient availability. Figure 5-4 shows the distribution of DIN at stations throughout Puget Sound. Stations were classified by calculating the number of months with DO less than 1.0 micromoles/liter in each year between 2001 and 2005 and reporting the highest value. Chronically

Figure 5-4. Occurrence of low dissolved inorganic oxygen at marine monitoring stations in Puget Sound, 2001-2005. Nitrogen is usually a limiting resource for phytoplankton growth, so chronically low DIN levels indicate that a water body may be susceptible to eutrophication. (Source: Ecology)

○ **Low** = <1.0 µm 5 month or more in a year

● **Moderate** = <1.0 µm 3-4 months or more in a year

● **High** = <1.0 µm 0-2 months in any given year



low concentrations of DIN in marine waters indicate that nutrient availability may be limiting phytoplankton production and, therefore, that the waters may be susceptible to eutrophication if additional nutrients are added.

Between 2001 and 2005, four stations had low DIN (< 1.0 µM) for five months or more. Two of these, south Hood Canal and Penn Cove, also had low DIN from 1998 through 2000. The other two stations, Saratoga Passage and Possession Sound, have had moderate DIN from 1998 through 2000. Overall, however, the number of stations that experienced an increase in low DIN occurrences equaled the number of stations that experienced a decrease in low DIN occurrences.

Ammonium is the form of nitrogen most easily taken up by phytoplankton. It enters marine waters from a variety of human and animal sources. Therefore, it provides an indication of nutrient availability and the proximity of an ammonium source that could cause eutrophication. Figure 5-5 shows the distribution of maximum ammonium concentrations measured at Puget Sound monitoring stations from 2001 through 2005.

Between 2000 and 2005, three stations had high (> 10 µM) ammonium concentrations: Budd Inlet's South Port station (which had high ammonium in 1998 through 2000), Quartermaster Harbor (which previously had moderate

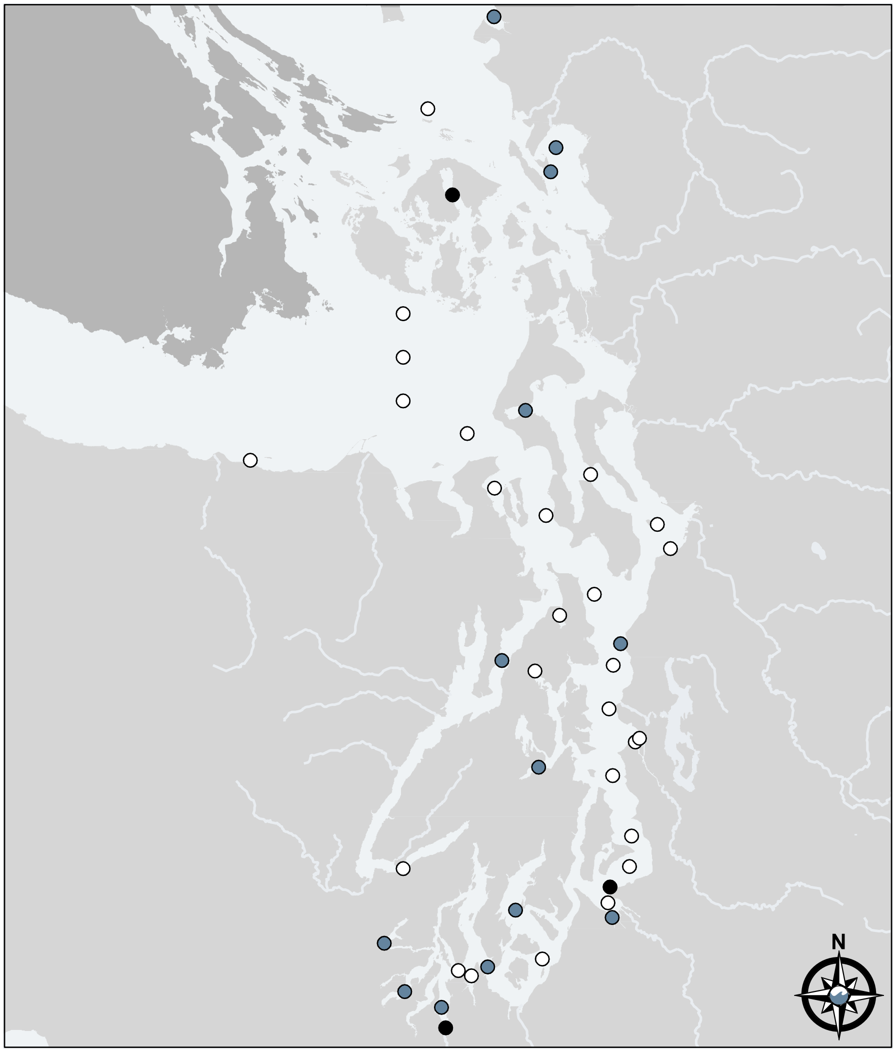


Figure 5-5. Maximum ammonium concentrations at marine monitoring stations in Puget Sound, 2001-2005. Ammonium is a nutrient that stimulates phytoplankton growth but can be toxic to marine life in high concentrations. Elevated concentrations of ammonium indicate the proximity of a nutrient source that could contribute to eutrophication.
(Source: Ecology)

- ● **High** = <10.0 µM
- ● Moderate = 5.0 - 10.0 µM
- ○ Low = > 5.0 µM

ammonium), and East Sound (which was not sampled in 1998 through 2000). Overall, eight stations had increases in ammonium concentrations: Penn Cove, Bellingham Bay (Pt. Frances), Nisqually Reach, Hood Canal (Bangor), Carr Inlet, Commencement Bay, Quartermaster Harbor, and Drayton Harbor. Five stations had decreases: Budd Inlet (Olympia Shoal), Possession Sound, Dana Passage, Port Orchard, and Bellingham Bay (Nooksack). As a result of these changes, stations with moderate ammonium concentrations were distributed throughout the Sound, rather than being clustered in the south Sound, as observed in 1998 through 2000. All levels measured are below the national water quality standards for ammonium. Trend analysis has not been done on the sites to determine overall changes over time. However, eight stations did show improvements in condition for ammonium while five declined during this period.

b. Eutrophication

The potential for eutrophication in Puget Sound depends on a variety of factors, including the strength and persistence of stratification, background concentrations of DO, and the susceptibility of the waters to increased phytoplankton growth due to nutrient additions. As a result, the risk of eutrophication can vary significantly in different parts of the Sound.

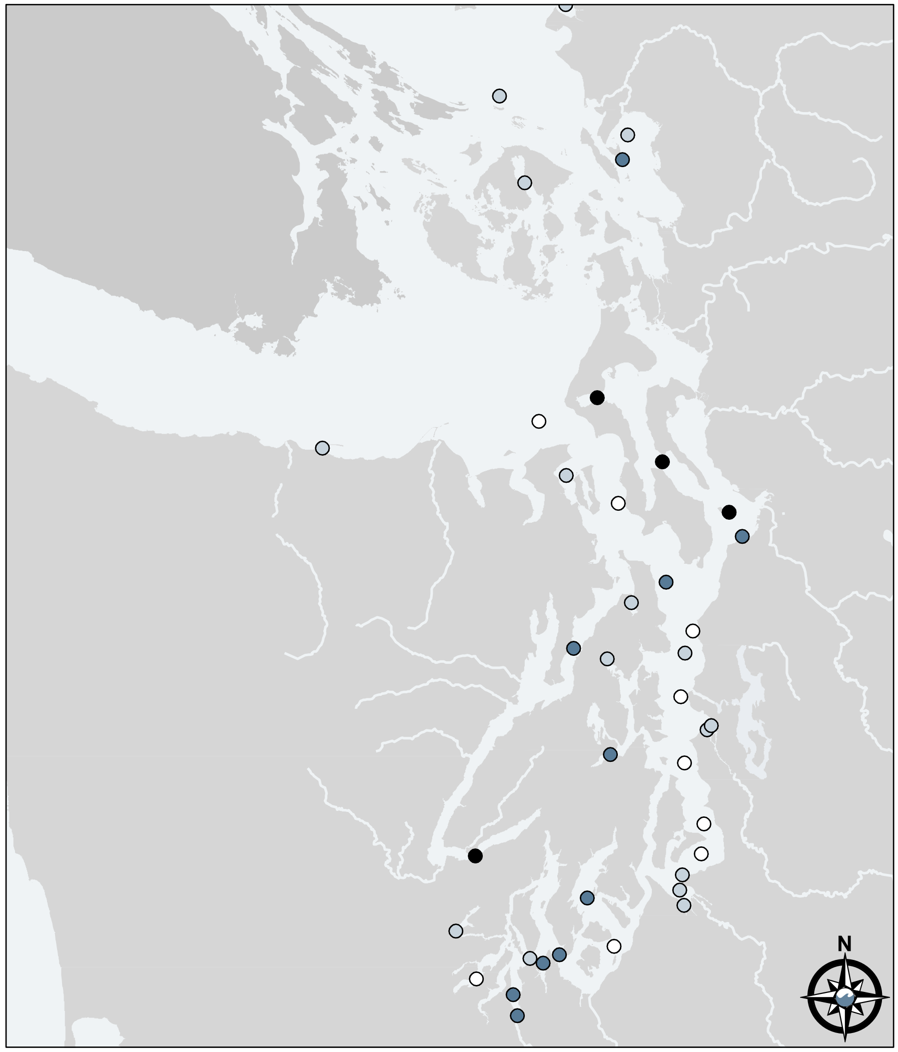


Figure 5-6. Index of sensitivity to eutrophication for Puget Sound marine water monitoring stations, based on 2001-2005 data. Stations are scored by assigning values to each of three indicators. Highest values are given to very low DO, strong stratification, and low DIN. Rankings of some stations were adjusted to reflect the influence of local factors, such as flushing time or susceptibility to eutrophication. Stations with very high sensitivity scored in all three indicators. (See Table 5-1 for individual station rankings.) This index provides a relative measure of sensitivity to water quality changes due to nutrient additions. In contrast, the water quality concern index (Chapter 3, Section g) combines the indicator results used here with information on maximum nutrient and fecal coliform concentrations to provide a measure of existing water quality conditions.
(Source: Ecology)

As discussed earlier, waters with chronically low DIN concentrations are usually more sensitive to nutrient additions than those with higher concentrations. In a stratified water column, high nutrient availability in surface waters can result in excessive phytoplankton growth, which sometimes takes the form of highly visible blooms. As the phytoplankton die and sink, their decomposition consumes oxygen, driving DO concentrations lower. Because strong, persistent stratification inhibits mixing, DO levels at depth can continue to decline until they harm other marine life in these areas. (The causes and consequences of low DO and strong stratification are presented in more detail in Chapter 4.)

Status and Trends

To assess differences in sensitivity to eutrophication and to highlight locations most at risk, PSAMP scientists used Ecology and King County data from 2001 through 2005 on DIN, stratification intensity and persistence, and DO concentrations to calculate each station's condition. Figure 5-6 shows an index of the susceptibility to eutrophication for these locations. To calculate the index, numerical scores were assigned to two threshold values for each indicator, and a total score for the three indicators was calculated (see Table 5-1 legend). Stations were then assigned to one of four risk categories. In a few instances (noted in the Table 5-1's footnote), stations were placed in higher or lower categories than the numerical results indicated, because of special considerations. These include the effects of high flushing rates, which are not incorporated into the index at this time. (Future revisions of the indices will incorporate more of these factors into the index.) Categorical values for the indicators at each station are shown in Table 5-1.

Stations in south Hood Canal, Penn Cove, and Possession Sound are at very high risk for eutrophication, as in the previous assessment. Saratoga Passage, which was formerly classified as high risk, is now considered to have very high risk because of declines in DO concentrations and an increase in the frequency of low DIN. Stations with high sensitivity included many enclosed or semi-enclosed urban bays with slow flushing, such as Budd Inlet, Port Gardner, Bellingham Bay, Nisqually Reach, Carr Inlet, Case Inlet, and Henderson Inlet.

In contrast to Puget Sound, most stations in Grays Harbor and Willapa Bay, on Washington's outer coast, have low to moderate risk of eutrophication (Table 5-1), even though some of them rank relatively high in the water quality concern index, presented in (Chapter 3, Section 6g). These differences reflect the impact of strong tidal flushing and relatively high exchanges of water with the Pacific Ocean coast, which reduce the residence time of water in the estuary and prevent or slow the build-up of very high nutrient concentrations. Nonetheless, if inputs of nutrients were to increase substantially, eutrophication could become a problem.

Table 5-1. Indicator results and sensitivity to eutrophication index for Puget Sound marine monitoring stations, 2001-2005. Index calculations are described in Figure 5-6 and text. Stratification rankings are Strong and Persistent (SP), Strong and Intermittent (SI), Moderate and Intermittent (MntI), Moderate and Infrequent (MI), and Weak and Infrequent (WI). (Source: Ecology)

[1]Station has been moved, because of Navy security restriction. Alternate sampling sites are located in areas with different physical characteristics, which may impact water quality observations. Station believed to be higher-risk, based on historical observations.

[2]Station located in enclosed or semi-enclosed water body; increased risk due to reduced circulation.

[3]Station located in shallow, well-flushed areas; reduced risk.

[4]Station located in well-mixed, well-flushed passage or basin; reduced risk.

Location	DO	DIN	Stratification	Sensitivity to Eutrophication
Saratoga Passage	Very Low	Low	SP	Very High
Possession Sound	Very Low	Low	SP	Very High
Penn Cove	Very Low	Low	SP	Very High
Hood Canal - Sisters Pt.	Very Low	Low	SP	Very High
Bellingham Bay - Pt. Frances	Very Low	Mod	SI	High
Budd Inlet - South Port	Very Low	High	SI	High
Budd Inlet - Olympia Shoal	Very Low	Mod	MI	High
Admiralty Inlet South	Very Low	High	SI	High
Port Gardner West	Low	High	SP	High
Nisqually Reach	Very Low	High	WI	High
Hood Canal - Bangor[1]	Low	High	M Int	High
Sinclair Inlet[2]	Low	Mod	MI	High
Carr Inlet[2]	Low	Mod	WI	High
Henderson Inlet[2]	Low	High	WI	High
Willapa Bay - S. Jenson Pt.	High	Low	WI	Moderate
Willapa Bay - Nahcotta Channel	High	Low	MI	Moderate
Strait of Georgia	Low	High	SI	Moderate
Quartermaster Harbor	Low	Mod	MI	Moderate
Port Gamble	Low	Mod	MI	Moderate
Point Jefferson	Low	High	SI	Moderate
Elliott Bay	Low	High	SI	Moderate
Commencement Bay - Browns Pt.	Low	High	SI	Moderate
Commencement Bay	Low	High	SI	Moderate
Bellingham Bay - Nooksack	Low	High	SI	Moderate
Willapa River - Raymond	High	High	SI	Moderate
Willapa River - John. Slough	High	High	SI	Moderate
Port Townsend	Low	High	MI	Moderate
Port Orchard	High	Mod	WI	Moderate
Port Angeles Harbor	Low	High	WI	Moderate
Oakland Bay	High	Mod	MI	Moderate
East Sound	Low	High	MI	Moderate
Drayton Harbor	High	Mod	M Int	Moderate
Dana Passage	Low	High	WI	Moderate
Willapa Bay - Toke Point[3]	High	Mod	MI	Low
Willapa Bay - Naselle River[3]	High	Mod	MI	Low
Grays Harbor - Chehalis River[3]	High	High	SP	low
Grays Harbor - Damon Pt. [3]	Low	High	MI	Low
West Point[4]	Low	High	MI	Low
East Passage[4]	Low	High	MI	Low
Admiralty Inlet - Quimper Pn.[4]	Low	High	MI	Low
Admiralty Inlet - Bush Pt. [4]	Low	High	MI	Low
Totten Inlet	High	High	MI	Low
Point Wells	High	High	MI	Low
Grays Harbor - South Channel	High	High	MI	Low
Gordon Point	High	High	WI	Low
Dolphin Point	High	High	MI	Low

c. Fecal Pollution in Shellfish Growing Areas

DOH classifies commercial shellfish beds according to requirements set by the National Shellfish Sanitation Program and conducts its water quality monitoring program in conjunction with PSAMP. This long-term monitoring data has been used to determine status and trends of shellfish growing areas in Puget Sound. The shellfish growing area classifications are based on intensive and systematic sampling of fecal coliform bacteria and shoreline surveys to identify significant sources of fecal pollution. DOH also conducts comprehensive monitoring for biotoxins and performs other targeted monitoring activities.

Status and Trends

DOH calculated growing area statistics (geometric means and 90th percentiles)[1] from more than 1,300 marine water sampling sites in 98 shellfish growing areas collected in 2005. Sites were grouped by year and by category—"Good," "Fair," or "Bad." The fraction of sampling stations within each category was used to produce a pie chart for each growing area. These pie charts provide a means to visually compare fecal pollution in the various shellfish growing areas of Puget Sound (Figure 5-7). There were 31 shellfish growing areas with significant fecal pollution impact.

A Fecal Pollution Index, (FPI) was calculated for each growing area. (For detailed information on how FPIs were calculated, see Determan, 2005). Figure 5-8 shows FPIs for the 31 shellfish growing areas with scores greater than 1.0 in 2005 (approximately a third of all areas). In 2005, Drayton Harbor showed the greatest fecal pollution impact (FPI = 2.75), followed by Port Susan (FPI = 2.40), and Padilla Bay (FPI = 2.19). These FPIs help confirm the visual information displayed in Figure 5-7. The ranking may be a useful tool in prioritizing resources for remedial action. Figure 5-9 shows FPI values for the six basins in Puget Sound.

Fecal Pollution in Historically Important Shellfish Areas.
A number of shellfish growing areas have received substantial federal, state, and local resources for remedial action for over a decade. FPIs were used to examine trends in several long-term project areas. Figure 5-10 shows annual standardized FPIs[2] from seven shellfish harvest areas in Puget Sound, ordered according to their 2005 FPIs. Henderson Inlet and Portage Bay show evidence of reduced fecal impact in recent years. This may be in response to several factors, including remedial action, annual rainfall, and changes in land use. For example, fecal pollution impact in Henderson Inlet closely follows annual rainfall and may be a stronger influencing factor than remedial action. However, the strength of interacting factors in fecal pollution has not yet been examined.

Annual standardized FPIs were also calculated from pooled results from all standardized stations throughout Puget Sound. The results suggest that overall fecal pollution impact in Puget Sound from 1998 through 2005 has been low and stable.

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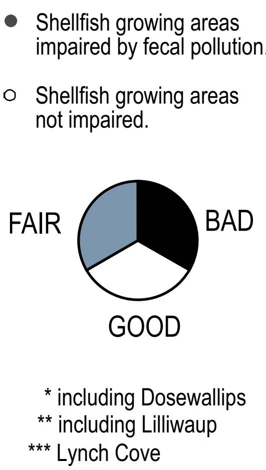
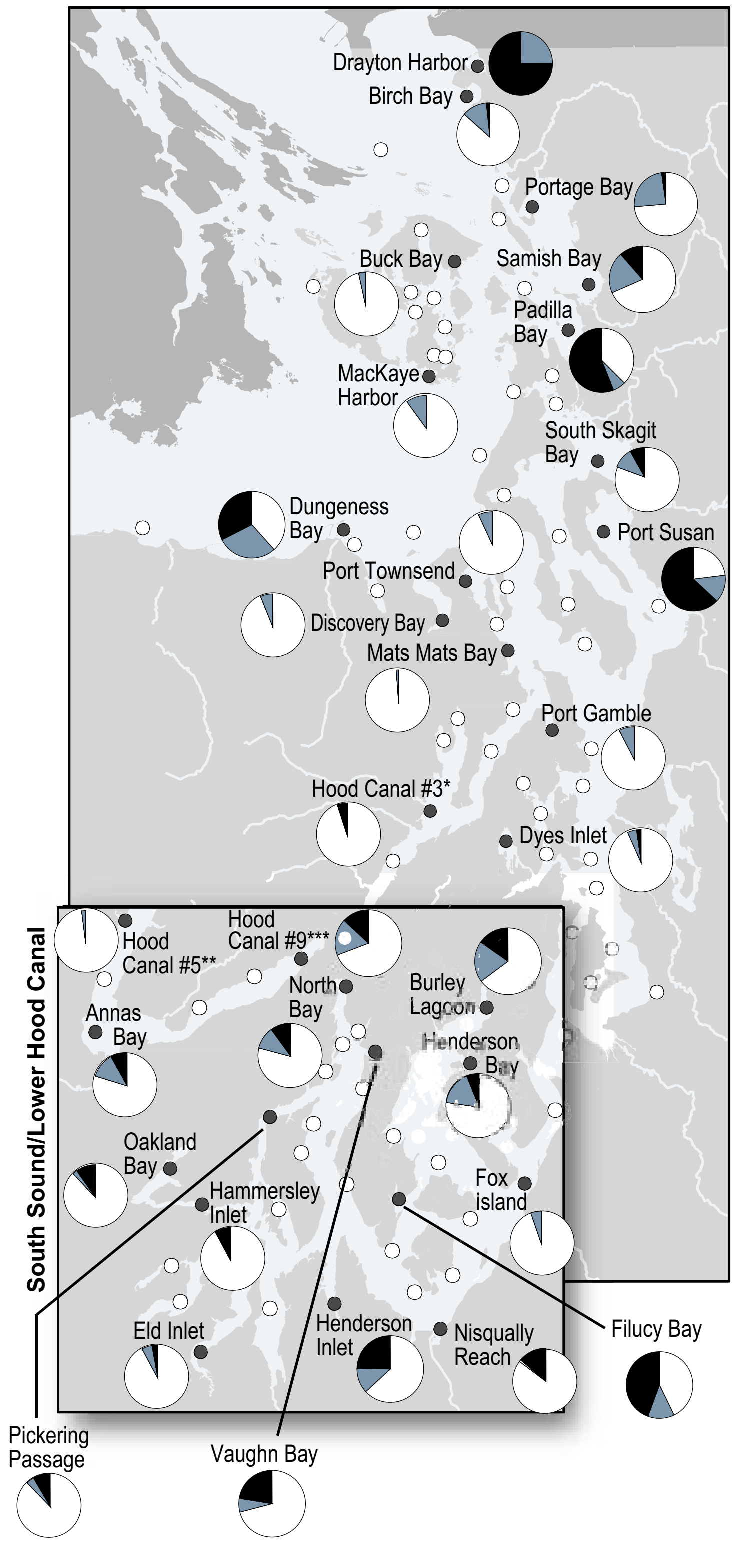
[1] The status of each growing area for calendar year 2005 was determined by sorting 90th percentiles from all sampling sites and sampling dates during the year into three categories: Good, Fair, or Bad. Each category is defined as follows:

- **Good** (0-30 MPN per 100 ml)
- **Fair** (31-43 MPN per 100 ml)
- **Bad** (greater than 43 MPN per 100 ml

[2] In order to assure accurate among-years comparison, each area was standardized, with only stations consistently sampled over the entire period of record used for FPI calculations. Thus, stations that were recently added or terminated were eliminated before FPIs were calculated. The annual FPIs were plotted as standard FPIs.

Figure 5-7: Status of fecal pollution in shellfish growing areas throughout Puget Sound and associated waters in 2005. The pie charts with greater proportions of black and gray represent areas most affected by fecal pollution. Thirty-one of the 98 shellfish growing areas were affected by fecal pollution. The most affected areas include three growing areas in north Puget Sound: Drayton Harbor, Port Susan, and Padilla Bay. Across the region, fecal pollution is generally low but widespread and highly variable.
(Source: DOH)





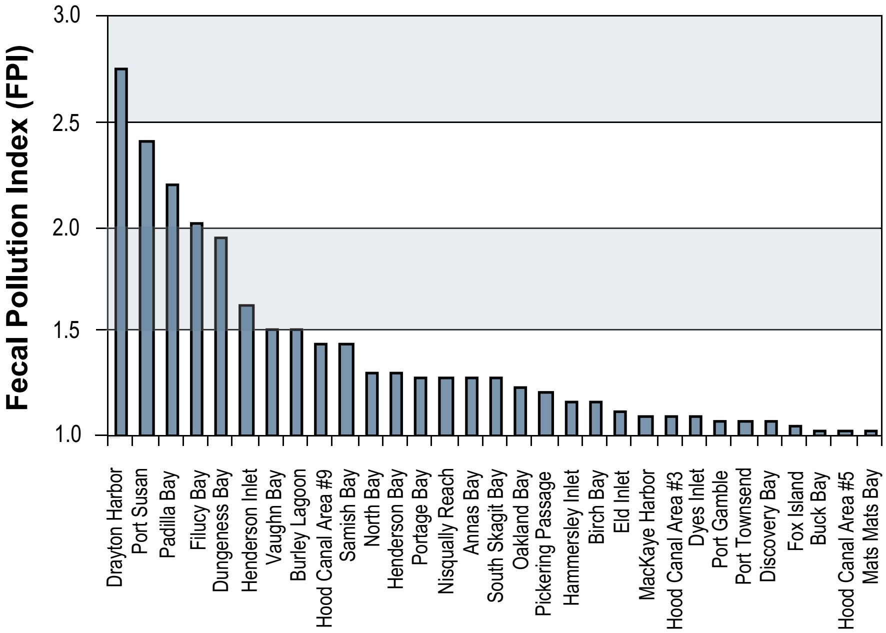


Figure 5-8. Index of fecal pollution in Puget Sound. A fecal pollution index (FPI) was used to rank 31 shellfish growing areas experiencing significant fecal pollution in 2005. The individual growing areas are ranked according to the degree of fecal coliform pollution impact, with Drayton Harbor showing the highest fecal pollution levels in Puget Sound.
(Source: DOH)

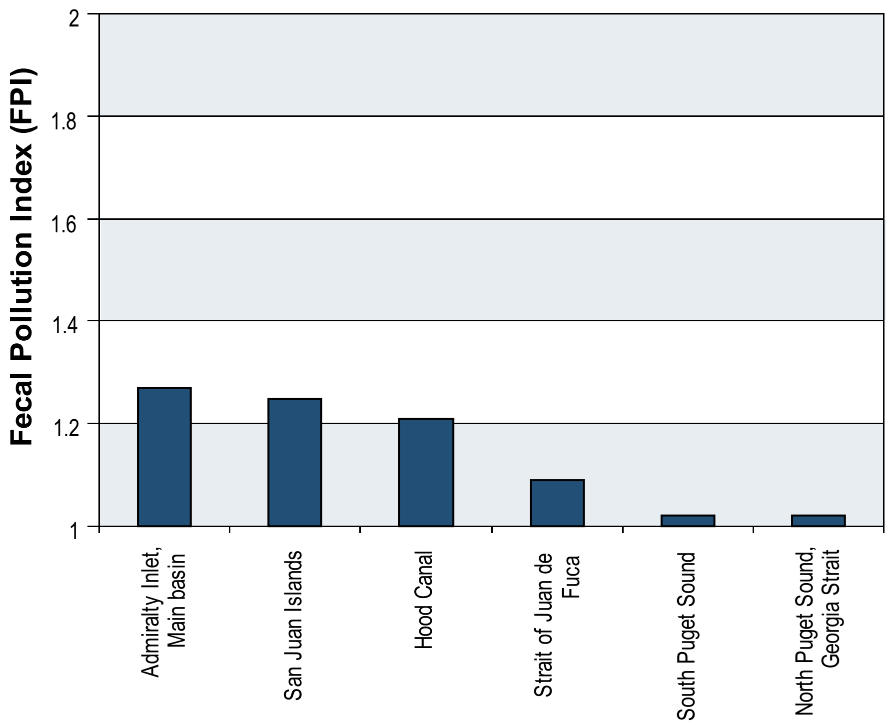
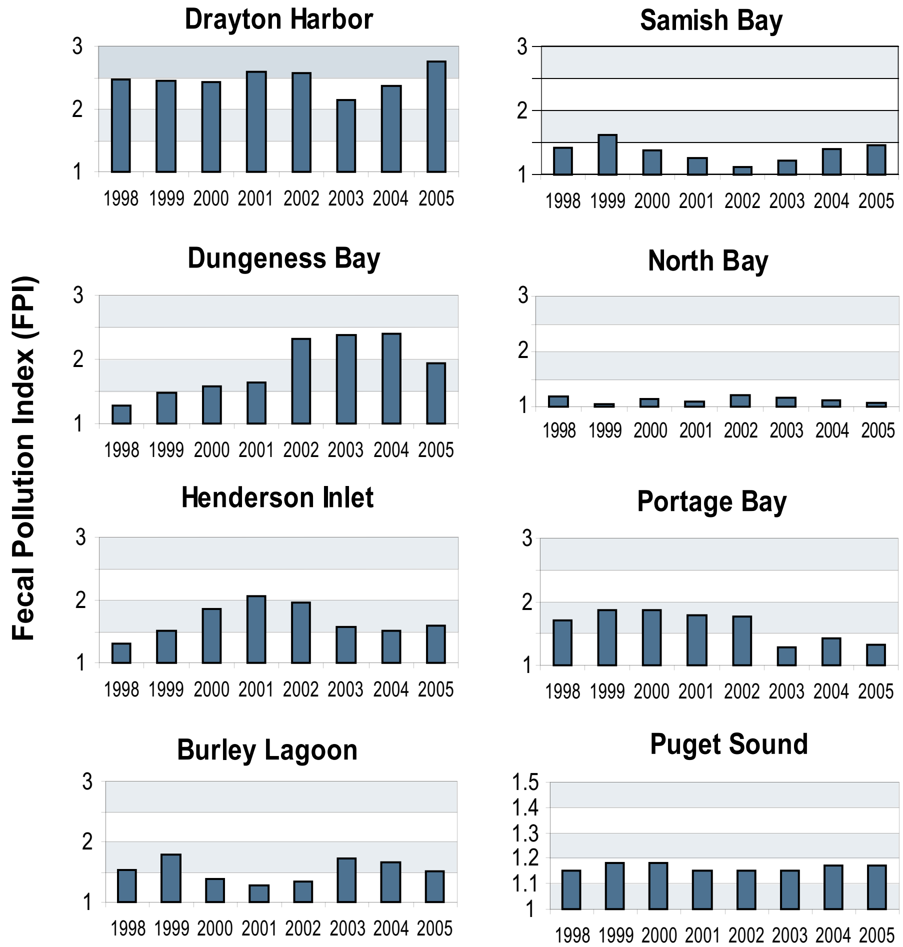


Figure 5-9. Fecal Coliform Index values for six major basins or regions in Puget Sound. North Puget Sound had the greatest impact, while Admiralty Inlet - Central Puget Sound the San Juan Islands were the lowest.
(Source: DOH)

Figure 5-10. Fecal coliform index trends in Puget Sound, 1998-2005. Standardized FPIs were used to indicate temporal trends in fecal pollution in eight shellfish growing areas that received remedial action over the years 1998-2005. Changes in fecal pollution impact are attributed to various interacting factors, including local rainfall patterns, change in land use, and intensity of remedial action. (Source: DOH)



Shellfish Growing Area Reclassification

During the past two decades, numerous growing areas have been downgraded by DOH, because of nonpoint fecal pollution. Local and state agencies subsequently investigated fecal sources in each associated watershed. Various processes have been undertaken to address pollution issues, including watershed management, intervention by local health authorities and conservation districts, shellfish closure response efforts, and Ecology's Total Maximum Daily Load program. In some instances, remedial action has led to upgrades of growing areas. Figure 5-11 summarizes reclassifications of shellfish growing areas in Puget Sound from 2001 to 2004 and also notes the key pollution sources.

Between 1995 and 2005, DOH reclassified more than 20 commercial shellfish growing areas in Puget Sound (Figure 5-12). During that period, over 12,500 acres (5,059 hectares) were upgraded and more than 5,000 acres (2,023 hectares) were downgraded, yielding a net gain of approximately 8,500 (3,440 hectares) commercial acres. The increase in harvestable acreage is the result of targeted efforts to protect and restore the Sound's valuable shellfish growing areas. The successes during this period take on added significance when compared with the region's population growth and development that continued to expand during this time frame.

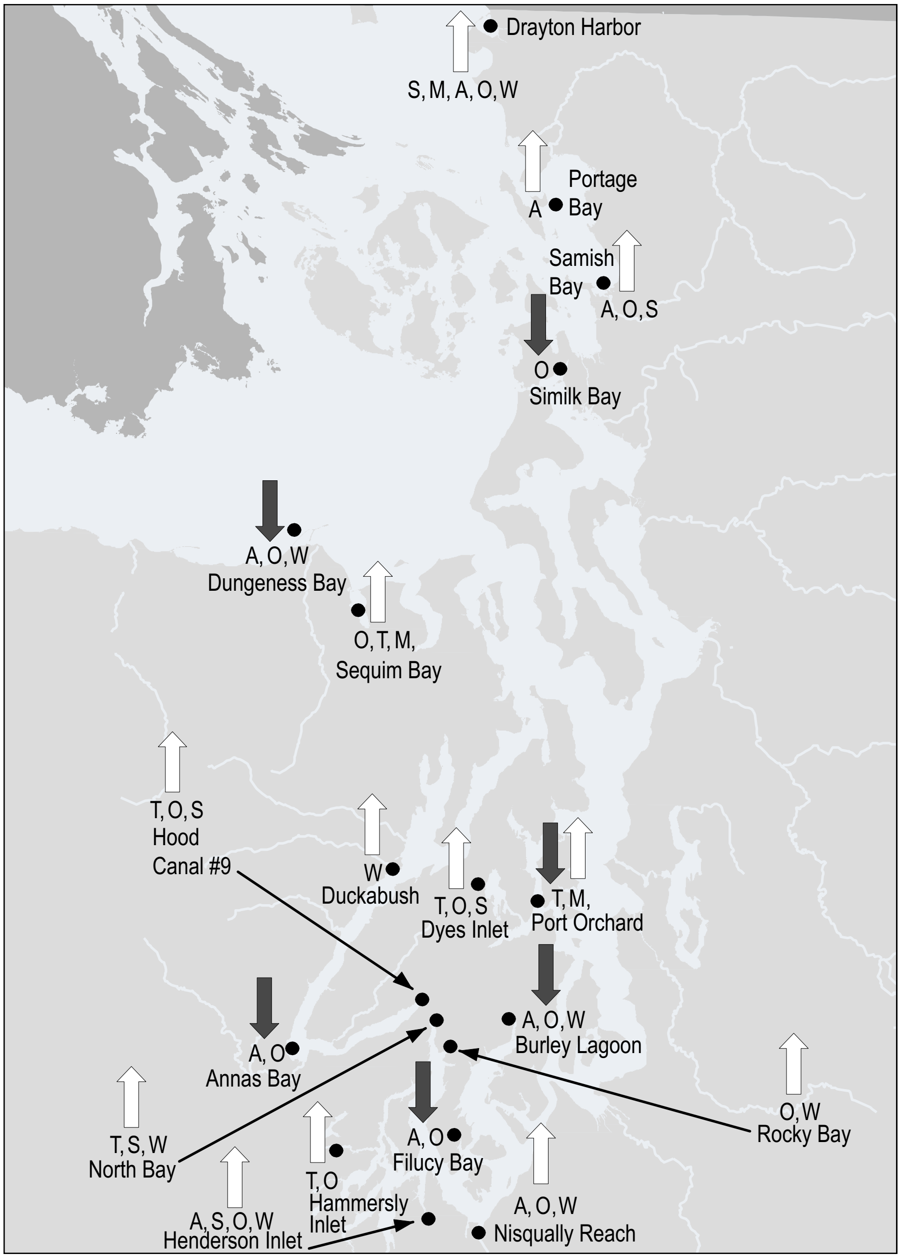


Figure 5-11. Shellfish growing areas in Puget Sound that have been reclassified or listed as threatened between 2001 and 2004. All areas are affected by nonpoint pollution sources (i.e., stormwater, agricultural runoff, and failing onsite sewage systems), therefore, conditions vary throughout Puget Sound. Some areas have improved because of local remedial action programs. Pollution sources listed have been identified and tracked. (Source: DOH)

Pollution Sources

O - Onsites
T - Treatment Plant
S- Stormwater
A- Agriculture
W- Wildlife
M - Marinas

Reclassification Type

Downgrade

Upgrade

d. Kitsap County pathogen study

Kitsap County Health District (KCHD) began water quality monitoring in 1996 in 10 watersheds throughout Kitsap County. The program included monitoring for fecal coliform bacteria in 55 streams, 67 marine stations, and 28 beaches. In addition, KCHD's Pollution Identification and Correction (PIC) Program was created to assist communities in the clean up of surface waters that had documented fecal coliform pollution problems. PIC staff visit homeowners and help identify potential pollution sources. They also educate homeowners on how to avoid contributing to pollution loads, including proper maintenance of onsite sewage (septic) systems. Over the past 10 years, PIC staff have inspected 4,827 individual properties and discovered 737 failing onsite sewage systems.

As of result of this program, four polluted shellfish harvesting areas were cleaned up and reopened: Burley Lagoon, Port Gamble Bay (Cedar Cove), Illahee State Park, and Dyes Inlet. To prevent additional inputs of fecal contamination, four sewage control devices were installed at Kitsap County marinas.

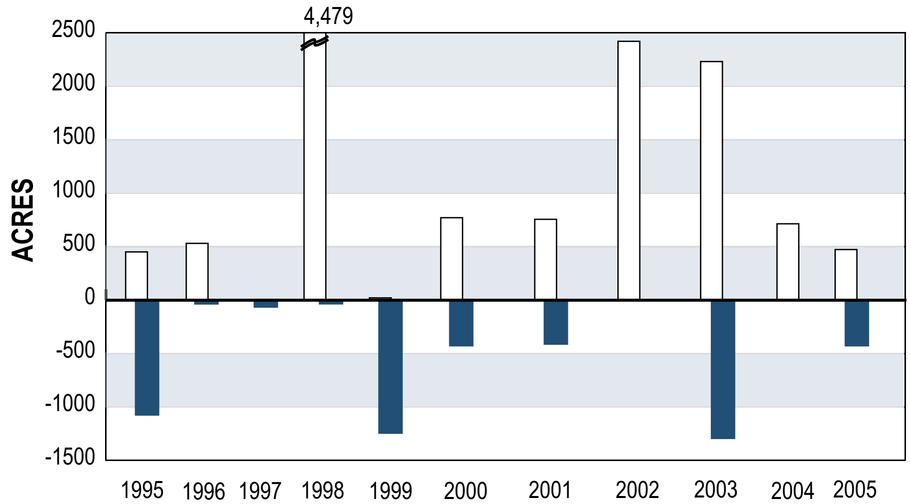


Figure 5-12: Puget Sound commercial shellfish reclassification, 1995-2005. The figure shows names and relative sizes of commercial shellfish growing areas reclassified by DOH (adapted from DOH 2005). Improvements in water quality and sanitary conditions allow DOH to reduce or remove harvest restrictions (upgrades), and declining conditions require DOH to restrict or close areas to harvesting (downgrades). The graph shows significant variability from year to year, but the trend in Puget Sound over the 11-year period has been generally positive, as restoration efforts have successfully outpaced downgrades in other areas. (Source: PSAT)

☐ Upgrades

■ Downgrades

** reclassifications associated with changes in sanitary conditions*

e. Monitoring for Fecal Pollution along Puget Sound Beaches

Ecology and DOH jointly administer the Beach Environmental Assessment, Communication and Health (BEACH) Program, an EPA-funded effort that monitors for fecal bacteria (enterococcus) at saltwater beaches used for swimming, surfing, scuba diving, wind surfing, and other water contact activities. The program also notifies the public if a beach is believed to have an increased risk of disease. The BEACH Program coordinates its activities with DOH's shellfish monitoring program.

King County also monitors its beaches for fecal contamination, mainly focusing on shellfish consumption risk. Although the health risks for consuming shellfish are evaluated differently than the risks for water contact activities, the BEACH Program and King County programs complement each other by providing comprehensive bacteria monitoring and public health evaluations at Washington's heavily used saltwater beaches.

i. Ecology's BEACH Program

The BEACH Program was developed in 2002 and full implementation began in 2004. Each year a risk-based system that considers use patterns and the proximity to significant sources of fecal pollution is used to select approximately 70 beaches for weekly monitoring during the summer, from Memorial Day through Labor Day. From 2002 through 2005, nearly 200 beaches have been evaluated and 104 beaches have been monitored. Figure 5-13 shows sampling locations in 2004 and 2005 and the number of exceedances during each season.

Status and Trends

In north Puget Sound, 25 beaches were sampled during the 2004-2005 period. This area does not usually have high bacterial counts, because of the existence of exposed beaches with strong currents and short retention times. Beaches that did have exceedances tended to be in communities that were largely on septic systems (Birch Bay County Park and Bayview State Park) or in small, enclosed bays, such as Freeland.

In the central Sound, 28 beaches were sampled in 2004 and 2005. This area tends to have the highest bacteria counts, primarily due to combined sewage overflows, aging infrastructure, and small enclosed bays with long retention times. Specifically, Dyes and Sinclair Inlets tend to have high numbers of exceedances.

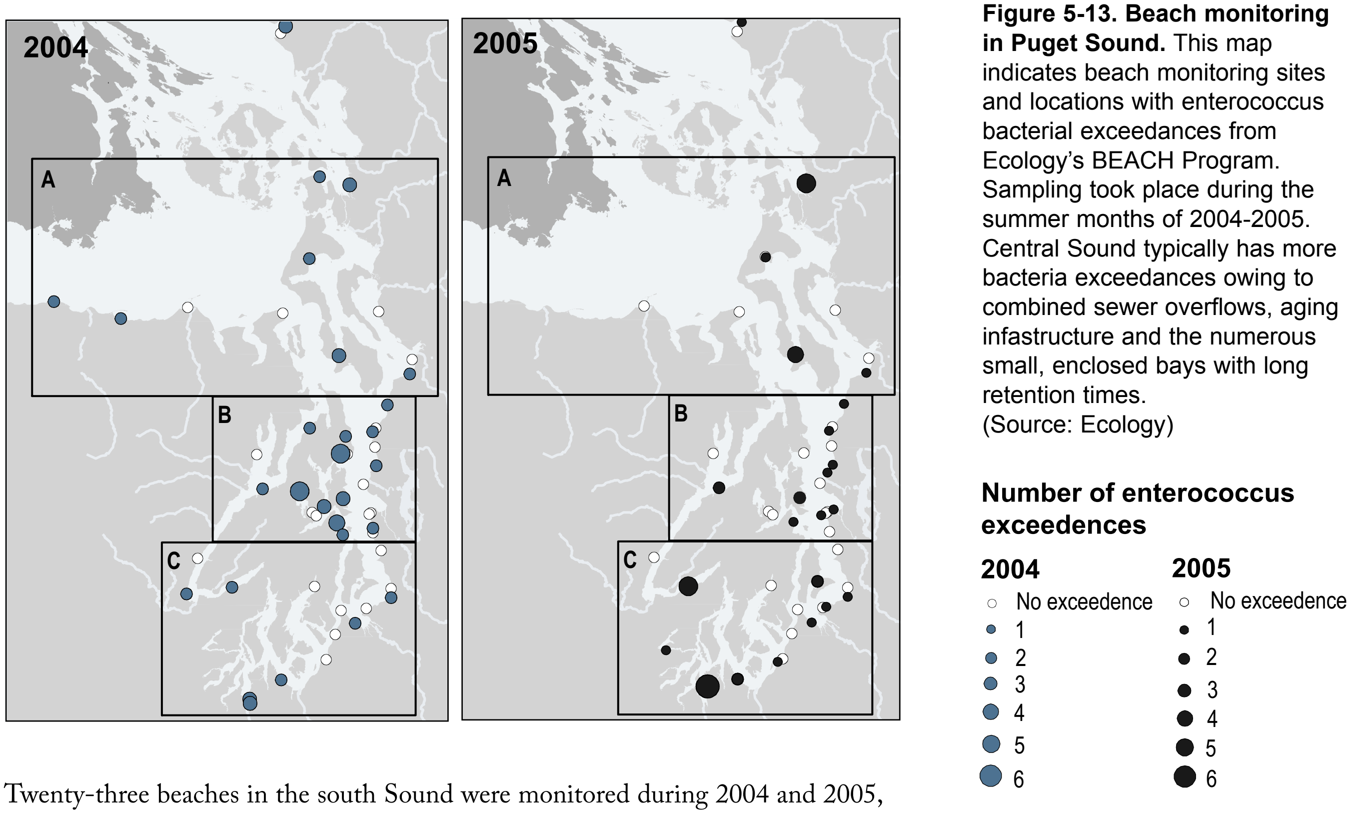


Figure 5-13. Beach monitoring in Puget Sound. This map indicates beach monitoring sites and locations with enterococcus bacterial exceedances from Ecology's BEACH Program. Sampling took place during the summer months of 2004-2005. Central Sound typically has more bacteria exceedances owing to combined sewer overflows, aging infastructure and the numerous small, enclosed bays with long retention times. (Source: Ecology)

Twenty-three beaches in the south Sound were monitored during 2004 and 2005, and the results indicate patchy bacterial exceedances attributed to site-specific problems. A failing septic pipe was identified as a source of high bacteria at Twanoh State Park in Hood Canal, and a failing treatment plant was identified as a source in Thurston County.

Human Health Implications

The BEACH Program notifies the public whenever high levels of bacteria or sewage spills are affecting monitored beaches. The number of beach closures caused by sewage spills has increased dramatically since 2003, which may be partly the result of better communication between state and local agencies, rather than an increase in the number of spills.

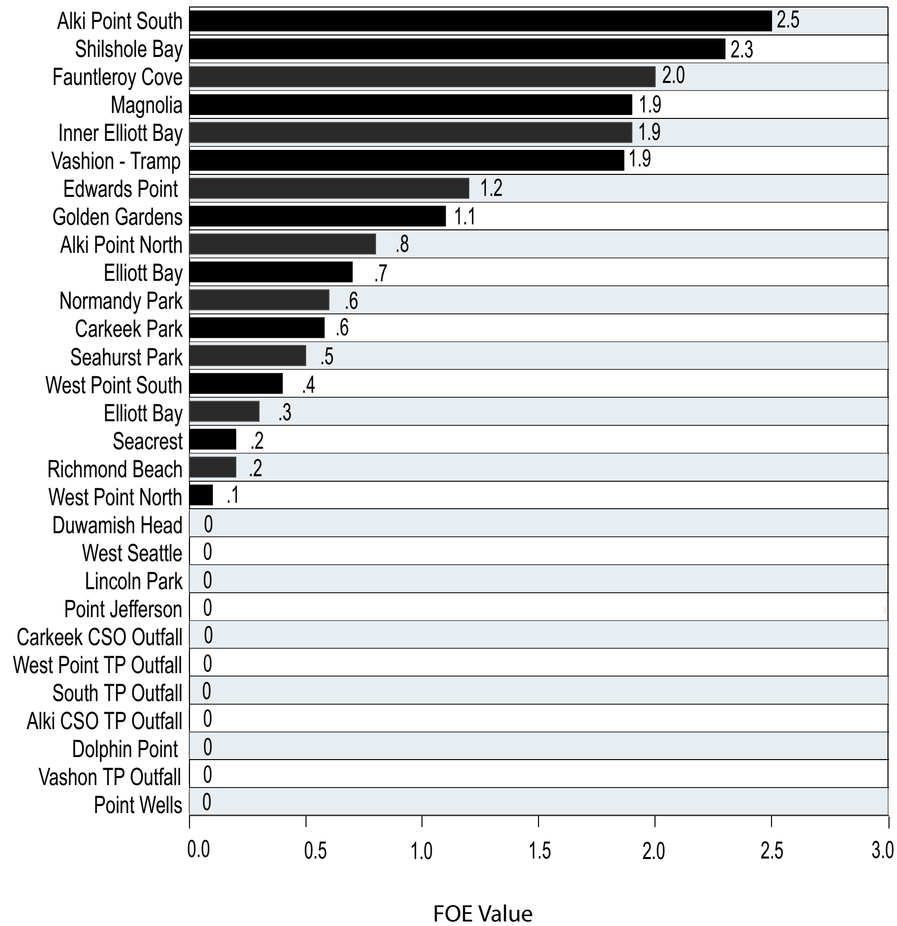
ii. King County's Beach Monitoring Program

Status and trends

Trend analyses of fecal coliform geometric mean values from more than 20 beach stations monitored by King County indicate that fecal pollution at these sites has been lessening since 1997. This may be attributable to changes in annual rainfall patterns. Seattle's Carkeek and Golden Gardens Parks, located north of the Ship Canal, consistently exceeded the water quality guidelines until mid-2002 and have since improved to acceptable levels. Stations in Magnolia, Alki Point, and Fauntleroy Cove show similar trends but still exceed water quality guidelines.

To rank the extent of fecal coliform levels at King County marine monitoring stations, a Frequency of Exceedence (FOE) Index was calculated for 20 King County beach and offshore stations sampled in 2004 (Figure 5-14). The FOE index is based on Washington State Department of Ecology water quality guidelines and represents the frequency with which a station exceeds fecal coliform bacteria state guidelines. The higher the value of the FOE Index, the more frequently a station has exceeded state guidelines for fecal coliform bacteria. The

Figure 5-14. Frequency of Exceeding (FOE) fecal coliform ranking at King County beaches. Sites are ranked according to their frequency of exceeding state guidelines for fecal coliform at King County beaches and offshore stations in 2004. The higher the value of the FOE Index, the more frequently a station has exceeded state guidelines for fecal coliform bacteria.
(Source: KC DNRP)



results of ranking stations by FOE index can be seen in Figure 5-14. Station LSKS01 near Alki Point is ranked as King County's most polluted station with respect to fecal coliform contamination. This station was persistently in exceedance of water quality guidelines by greater than two times for the entire year. With the exception of LTEH02 and LTED04, both in Elliott Bay, all offshore and outfall stations had the lowest FOE index for fecal coliforms.

Monitoring for Fecal Coliform at Public Shellfish Beaches

In addition to monitoring water quality at beaches for fecal pollution to protect human health, the State also monitors beaches for fecal coliform bacteria and biotoxins in shellfish harvest areas. In 2005, over 450,000 recreational shellfish licenses were sold in Washington. DOH works cooperatively with WDFW, local health jurisdictions, tribes and other stakeholders to classify beaches and educate the public regarding their personal responsibility for safe shellfish harvests and consumption.

Currently, 251 recreational beaches are classified as "Open," "Conditionally Open," "Advisory," or "Closed." Monitoring and classification efforts focus on areas with significant shellfish resources and harvest activity (more than 500 people per year). Between 2004 and 2005, seven local health jurisdictions requested that DOH classify 13 recreational shellfish beaches. As with commercial shellfish areas, recreational classification must meet the standards of the National Shellfish Sanitation Program.

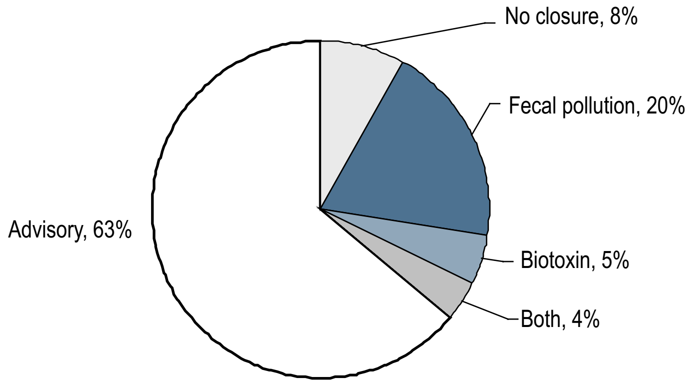


Figure 5-15. **Closure status of all Puget Sound recreational shellfish beaches as of May 31, 2006**. Status can change daily because of marine biotoxin or pollution events.
(Source: DOH)

County	total	No Closure	Pollution	Biotoxin	Both	Advisory
Clallam	29		5	4	8	12
Island	56	5	17			34
Jefferson	47	5	7	3	1	31
King	22		13		3	6
Kitsap	30	3	11	3	2	11
Mason	36	4	9			23
Pierce	33	8	6			19
San Juan	123	3	1			119
Skagit	21		4	10		7
Snohomish	7	1	4		2	
Thurston	6	2	3		1	
Whatcom	18	3	4			11
Total	**428**	**34**	**84**	**20**	**17**	**273**

Table 5-2 Closure location and status of recreational shellfish beaches in 12 Puget Sound counties as of May 31, 2006. The table indicates the wide range of available recreational beaches and the diversity of factors controlling their availability for shellfish harvest. (Source: DOH)

Notes: Status can change daily due to marine biotoxins or pollution events.

No Closure: Beaches that were currently not closed as of May 31, 2006.

Pollution: Beaches that are closed due to known or likely sources of contamination from human or animal waste as of May 31, 2006.

Biotoxin: Beaches that were closed due to biotoxins (PSP, domoic acid) as of May 31, 2006.

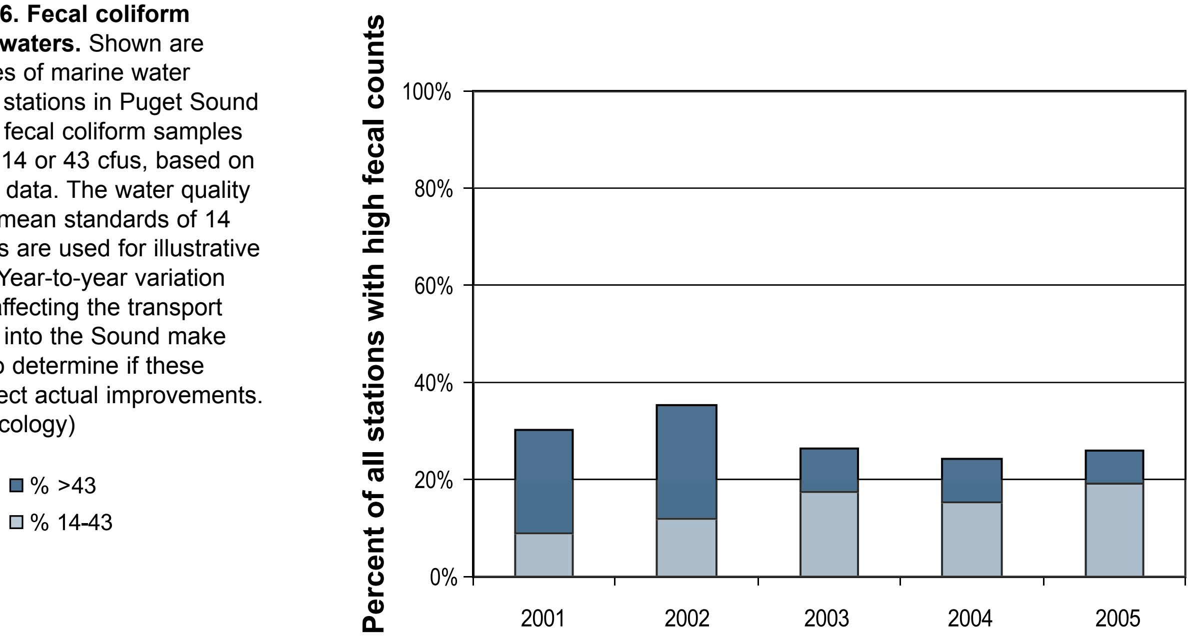
Both: Beaches closed by both health threats as of May 31, 2006.

Advisories: Beaches that are unclassified; possess seasonal closures (i.e., marinas, *Vibrio)*; or pollution events are too unpredictable (rainfall, combined sewer overflows, etc.).

All 12 local health jurisdictions in Puget Sound manage the recreational shellfish beaches in their areas. DOH works closely with the jurisdictions, parks administrators, and other stakeholders to provide program guidance, beach signs, and educational materials.

The current closure status for 428 recreational shellfish beaches in Puget Sound is listed in Table 5-2. Figure 5-15 summarizes this information for all beaches in Puget Sound, indicating that about 20 percent of shellfish on recreational beaches are affected by fecal pollution. Fecal pollution tends to be somewhat localized in adjacent uplands and, thus, can be controlled. In contrast, marine biotoxins (such as domoic acid) and diseases (such as vibriosis from *Vibrio* bacteria) are subject to more regional or global factors and, thus, are unlikely to be eliminated by remedial action. More than 60 percent of beaches have advisories, due to a variety of factors, including a lack of information (unclassified status), seasonal closures, or pollution events that are too unpredictable (e.g., rainfall or combined sewer overflows).

Figure 5-16. Fecal coliform in marine waters. Shown are percentages of marine water monitoring stations in Puget Sound with single fecal coliform samples exceeding 14 or 43 cfus, based on 2001-2005 data. The water quality geometric mean standards of 14 and 43 cfus are used for illustrative purposes. Year-to-year variation in factors affecting the transport of bacteria into the Sound make it difficult to determine if these results reflect actual improvements. (Source: Ecology)



f. Fecal Coliform Bacteria in Marine Waters

Ecology uses individual monthly samples, collected at open-water stations, to identify high fecal coliform concentrations for its long-term marine monitoring program. State standards for fecal coliform bacteria in marine waters dictate that the mean (geometric) of multiple samples cannot exceed 14 colonies/100 ml, and that not more than 10 percent of these samples can exceed 43 colonies per 100 ml. For simplicity of presentation, these limits are used to categorize fecal coliform, based on individual samples in this document.

Status and Trends

The percentage of stations with moderate (>14 cfu per 100 ml) or high (>14 and > 43 cfu per 100 ml) maximum fecal counts from 2001 through 2005 are presented in Figure 5-16.[3] These results are consistent with a general decline in fecal coliform contamination noted in the *2002 Puget Sound Update*, but, because there is considerable year-to-year variation in factor affecting the transport of bacterial pollution into Puget Sound, further monitoring is required to determine if these results represent actual improvements.

The maximum fecal coliform bacteria concentrations observed at stations throughout Puget Sound between 2001 and 2005 and classified using the same criteria discussed previously are shown in Figure 5-17. The highest levels of fecal contamination were observed in Budd Inlet, Commencement Bay, Oakland Bay, Port Angeles Harbor, Possession Sound, Elliott Bay, and off West Point. Moderately high levels of contamination were observed in Admiralty Inlet, Bellingham Bay, Sinclair Inlet, and off Point Jefferson. In general, these results are similar to those from 1998 through 2000 and reflect the fact that fecal coliform contamination is typically associated with large urban areas, those areas adjacent to intense shoreline development, or near enclosed or semi-enclosed inlets with slower flushing times.

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[3] State standards for fecal coliform bacteria in marine waters dictate that the geometric mean of multiple samples cannot exceed 14 colonies/100ml and that not more than 10 percent of these samples can exceed 43 colonies/100ml. For simplicity of presentation, these limits are used to categorize fecal coliform, based on individual samples.

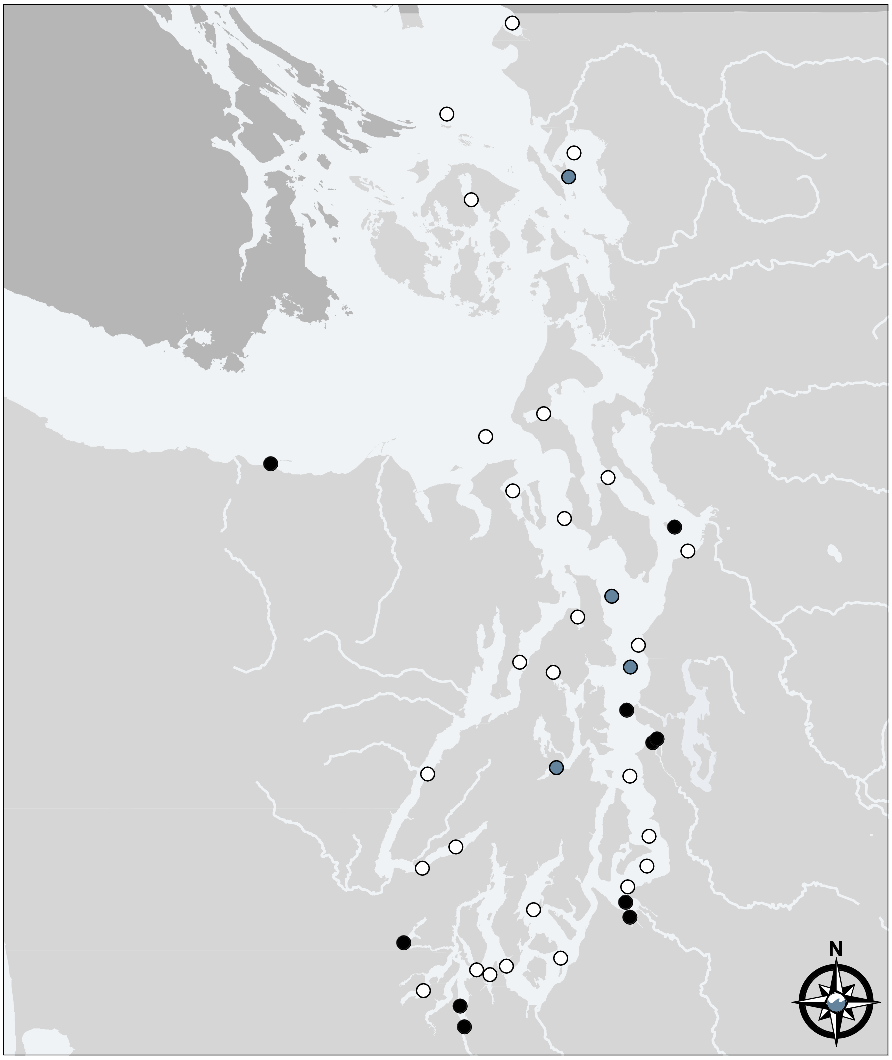


Figure 5-17. Distribution of maximum fecal coliform bacteria counts at marine monitoring stations in Puget Sound, 2001-2005. High fecal coliform counts indicate the presence of a nearby source of fecal coliform bacteria and, possibly, other contaminants. (Source: Ecology)

- High (> 43 cfu/100ml)
- Moderate (14-43 cfu/100ml)
- Low (< 14 cfu/100ml)

Declines in both fecal coliform and ammonium, both byproducts of animal waste, were observed at DOH's Bellingham Bay-Nooksack station. In 2003, DOH upgraded a portion of Portage Bay in Bellingham Bay as a result of reduced fecal pollution. This upgrade could be related to a remediation program involving a number of agencies and organizations to prevent and control fecal pollution from many sources, with control measures including better management practices at dairies in the Nooksack River watershed.

g. Circulation Modeling in Oakland Bay and Hammersley Inlet

The City of Shelton needed to increase the discharge from its wastewater treatment plant but did not want to compromise economically important shellfish harvest areas. DOH approached Ecology in 2002 to develop a computer model of Hammersley Inlet and Oakland Bay that could be used to evaluate the effectiveness of various discharge scenarios. The use of computer circulation models provides an excellent, cost-effective way to evaluate the possible outcomes of different management actions on marine water bodies.

To address DOH's request, Ecology developed the three-dimensional Hammersley Oakland Bay Oceanographic circulation model. The approach taken to evaluate discharge scenarios also included a dye-release study to determine the amount of dilution between the existing outfall and the boundaries established to protect the shellfish beds (See Figure 5-18 in Appendix C, Color Figures). Dye was released at one hour past low slack tide and at two hours past low slack tide. The model was tuned to recreate the amount of dilution observed during the dye experiment and used to determine if various discharge scenarios would meet required water standards for fecal coliform bacteria.

The study, which was also supported by FDA and the City of Shelton, was a factor in DOH's decision to reopen a portion of the shellfish growing area in Hammersley Inlet. It also provided guidance for planned treatment plant upgrades, which include improvement of the outfall, installation of an effluent detention basin for controlling the timing of discharges, and a permit limit on the amount of effluent that could be discharged.

6. Harmful Algal Blooms

a. Biotoxins

Harmful algal blooms (HABs) in Puget Sound are those that can cause PSP and ASP. To detect the occurrence of these forms of poisoning, DOH monitors biotoxins in shellfish species from many locations throughout Washington's marine waters. In Puget Sound, DOH samples mussels biweekly for PSP and domoic acid at sites that are part of its Sentinel Monitoring Program. When shellfish show harmful levels of either biotoxin, DOH issues warnings to commercial and tribal growers, recreational beach managers, and local health agencies.

Status and Trends

There has been a documented spread in the occurrence of PSP throughout Puget Sound (Trainer et al. 2003) and formal shellfish closures that first began in the 1950s in areas of north Puget Sound in Sequim Bay, Discovery Bay, and the San Juan Islands. The first closures inside the main basin of Puget Sound were reported in 1978 when a large bloom event followed a late-summer warm spell and heavy rains. PSP illnesses were reported from Saratoga Passage to Vashon Island. The gradual, southward spread of PSP closures continued with increased incidents during the 1980s and 1990s. In 2000, seven people were stricken with PSP from mussels collected in Carr Inlet in South Puget Sound.

Diatoms in the genus *Pseudo-nitzschia* can produce the ASP-causing toxin domoic acid, which can accumulate in shellfish and other organisms to levels dangerous to human and marine life. In the fall of 1991, DOH found domoic acid in razor clams along Washington's ocean coast. Shellfish closures due to domoic acid levels are presently not uncommon and can be fairly chronic on Washington's ocean coast. Prior to 2003, domoic acid had not been detected at closure levels within Puget Sound, although *Pseudo-nitzschia* and domoic acid had been documented in Hood Canal (Horner et al.1996). In 2003, the first shellfish closure attributed to domoic acid occurred near Port Townsend in north Puget Sound.

In 2005, elevated levels of domoic acid prompted shellfish closures in Sequim Bay, Penn Cove, Saratoga Passage, and Holmes Harbor. The factors prompting such blooms and domoic acid production are current topics of research, to better understand, for example, why the concentrations of *Pseudo-nitzschia* do not correlate with the amounts of domoic acid found in shellfish (Trainer et al. 2000; 2002).

Harmful algae in Puget Sound

Phytoplankton are single-celled, free-floating plants (algae) in marine waters. A harmful algal bloom contains species of algae that produce biotoxins. When sunlight and nutrients are optimal, blooms of phytoplankton occur. Shellfish may concentrate dangerous levels of biotoxin while feeding during a bloom. Blooms of certain phytoplankton are known to harm humans, marine mammals, and birds. Two harmful algae are found in Puget Sound. The dinoflagellate *Alexandrium catenella* produces a family of saxitoxins, known collectively as PSP toxin. Symptoms of PSP range from numbness of the lips, face, and extremities, to respiratory arrest and death. There is no known antidote.

The second harmful algae is *Pseudo-nitzschia,* which produces domoic acid. Diatoms of this genus are an unfortunate recent arrival to Puget Sound from Pacific Ocean coastal waters. Gastrointestinal distress occurs within 24 hours after eating domoic acid-contaminated shellfish. Other reported symptoms include dizziness, headache, disorientation, and permanent short-term memory loss. In severe cases of ASP, seizures and death may occur.

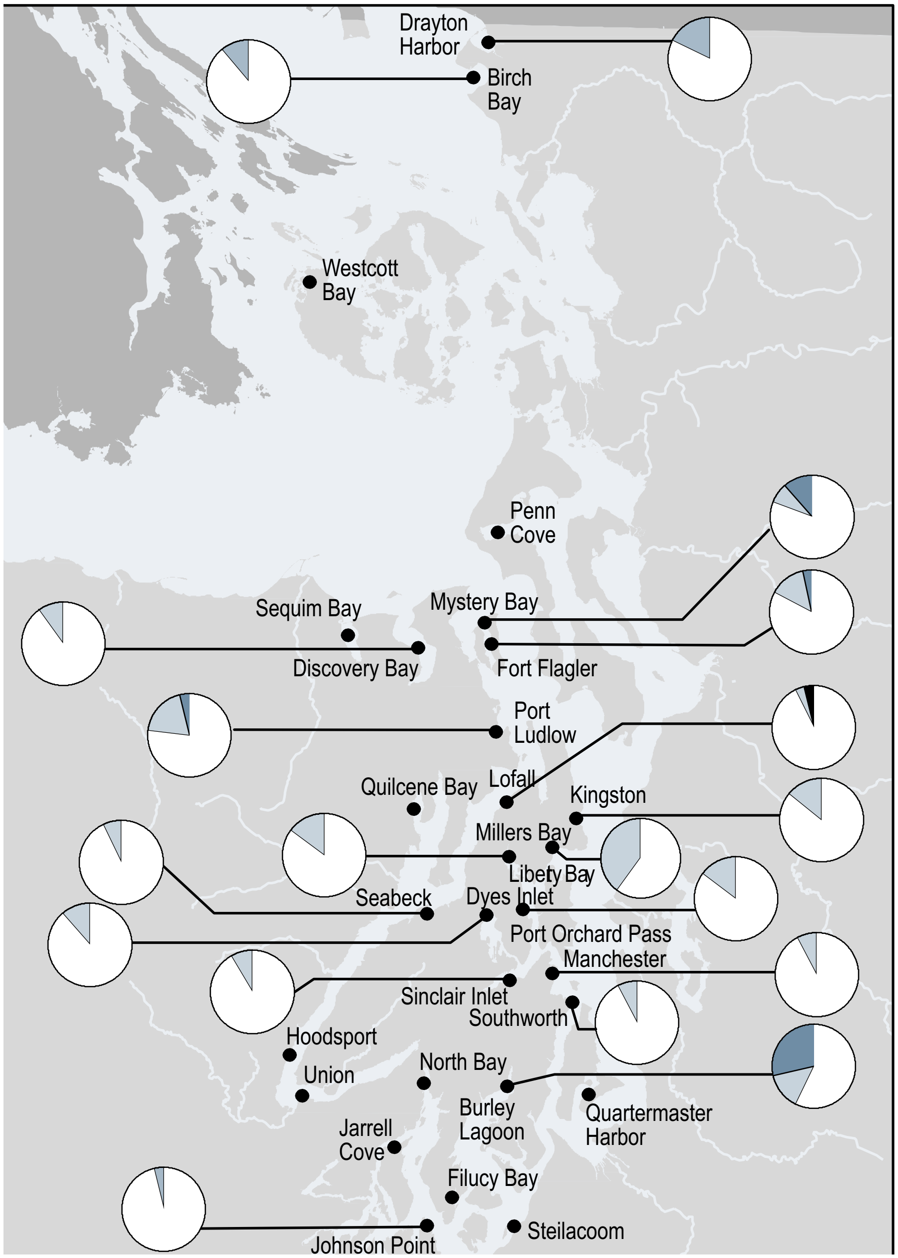


Figure 5-19. Paralytic Shellfish Poisoning (PSP) activity at PSP monitoring sites in Puget Sound. Pie charts estimate time per year each site was within a PSP impact category. Those sites with no pie chart did not experience PSP in 2005. (Source: DOH)

PSP Impact Categories

- None (PSP less than 80 ppb)
- Low (PSP 80 -499 ppb)
- Moderate (PSP 500 -999 ppb)
- High (PSP greater than 1000 ppb)

b. Paralytic Shellfish Poisoning

Status and Trends

In 2005, DOH examined results from 29 sentinel monitoring sites for spatial and temporal trends in PSP. The spatial distribution of PSP in Puget Sound is shown in Figure 5-19. Results were sorted into PSP impact categories (defined in the figure's legend) at each site. A pie chart summarizes the fraction of results in each impact category. Eighteen of 29 sites (62 percent) had at least minimal PSP impact.

The 18 sites affected by PSP were ranked, using a PSP Impact Index[4], which ranges from 1.0 (100-percent "Low" results) to 3.0 (100-percent "High" results).

[4] To calculate the PSP Impact Index, PSP results were sorted according to impact category (Low, Moderate, and High). The fraction in each category was then weighted (i.e., Low fraction x1; Moderate fraction x 2; High fraction x 3). The PSP Impact Index is the sum of the weighted values.

Figure 5-20. Ranking of 18 of 29 individual paralytic shellfish (PSP) poisoning sampling sites impacted in 2005. The PSP Impact Index ranges from 1.0 (100=percent Low results) to 3.0 (100=percent High results). Most sites fall within Medium to Low impact ranges. (Source: DOH)

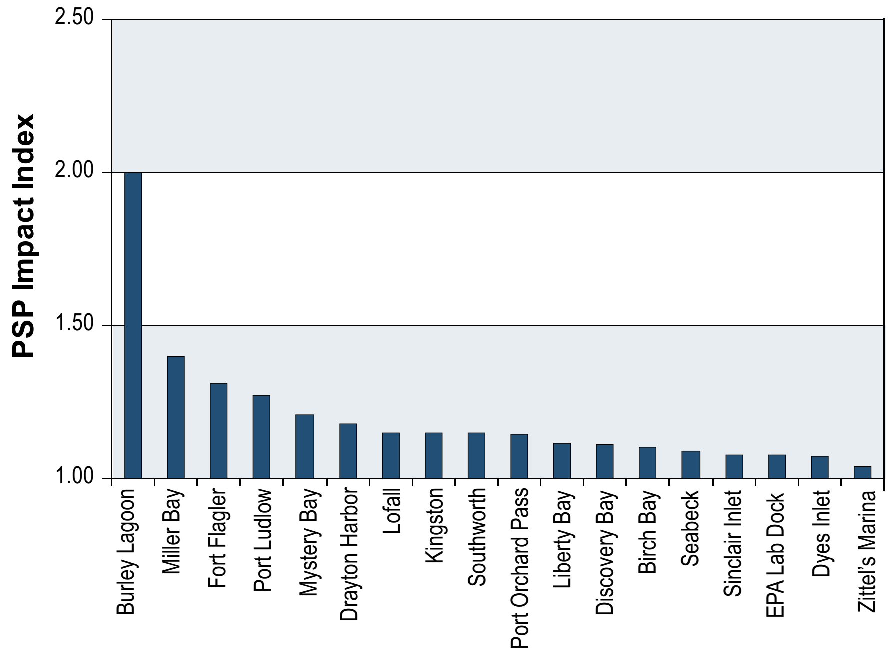


Figure 5-20 ranks the 18 sites according to the intensity of PSP activity. Burley Lagoon (in the South Puget Sound Basin) ranked highest in 2005, according to the PSP Impact Index.

The concept of the PSP Impact Index was extended to describe temporal tends in PSP activities in Puget Sound from 2001 through 2005. PSP impact indices were calculated, using results from all sites within each of five regions of Puget Sound and Soundwide (Figure 5-21) for each year from 2001 through 2005. The data suggest that, over the past five years, PSP activity was lowest in 2003 in four of five regions and overall in Puget Sound. PSP activity appears to have dropped significantly in 2005 in the Strait of Juan de Fuca, Admiralty Inlet, and the Central Puget Sound Basin. However, PSP activity was higher in 2005 in Georgia Strait and south Puget Sound. PSP activity in Hood Canal recently occurred for the first time in five years with blooms in Lofall and Seabeck.

c. Domoic Acid in Puget Sound

Status and Trends

In September, 2003, a *Pseudo-nitzschia* bloom occurred near Fort Flagler State Park on Marrowstone Island in Jefferson County. Subsequently, domoic acid was detected in mussels from the sentinel mussel cage at Fort Flagler, at levels slightly above the FDA domoic acid action level of 20 ppm in shellfish. DOH initiated closures for commercial and sport shellfisheries in the Fort Flagler area. Although the bloom was short-lived, low levels of domoic acid were detected as far west as Port Angeles, as far east as east Whidbey Island, and as far south as Port Ludlow (Figure 5-22).

In October 2005, levels of domoic acid detected in mussels from Penn Cove and clams from Holmes Harbor exceeded the FDA standard for PSP, prompting new closures. This time, levels were higher than first recorded in 2003. Domoic acid was also detected in Dungeness crab, below the FDA action level of 30 ppm for crab meat. Consequently, the crab fishery was not closed.

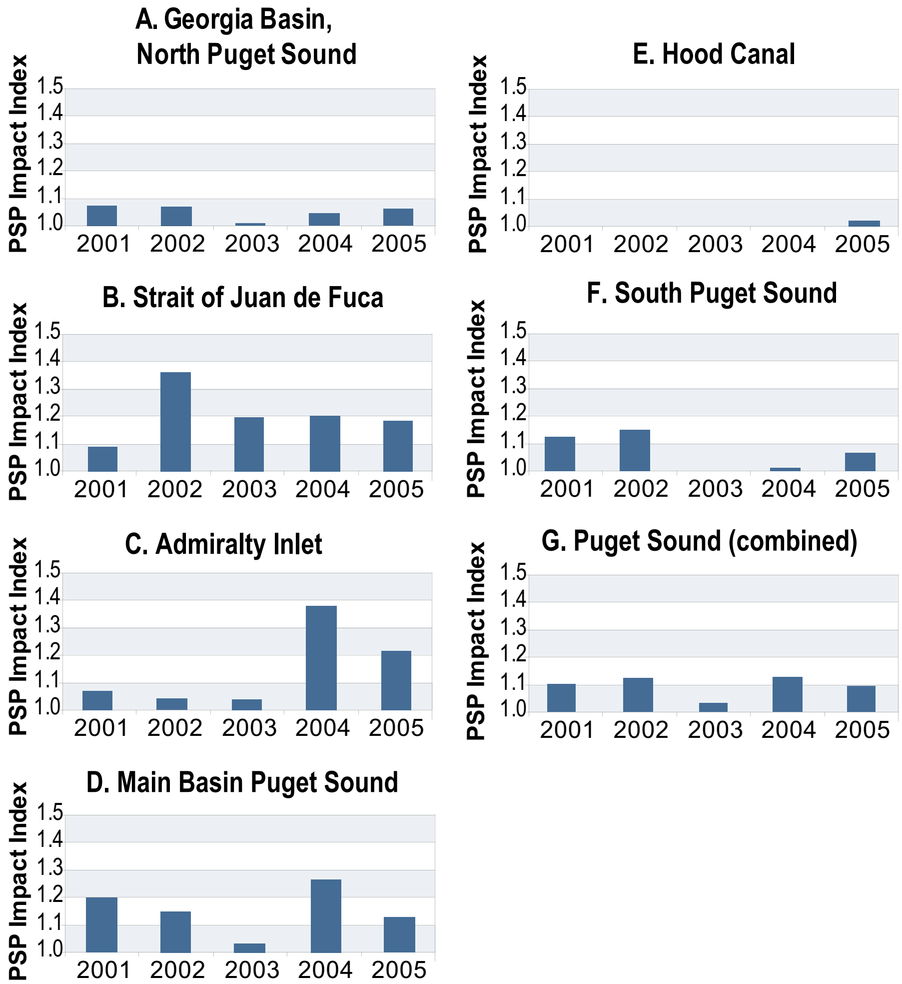


Figure 5-21. Trends in Paralytic Shellfish Poisoning (PSP) in Puget Sound. Temporal trends in PSP intensity from 2001 through 2005 in five regions of Puget Sound and through all of Puget Sound combined. The data suggest that PSP activity in the last five years was lowest in 2003 in regions a, s, d, and f and overall in Puget Sound. PSP activity appears to have dropped significantly in 2005 in the Strait of Juan de Fuca, Admiralty Inlet, and the Central Puget Sound Basin. However, PSP activity was higher in 2005 in the Georgia Strait and Puget Sound. (Source: DOH)

7. Natural Pathogens

a. Vibrio

Vibrio parahaemolyticus is a bacteria that naturally inhabits coastal marine waters. Its pathogenic mechanisms are not completely understood. DOH routinely analyzes oyster samples for presence of *V. parahaemolyticus* colony.

From May through September, DOH obtains oyster samples for laboratory analysis at least every other week from selected harvest sites in Puget Sound. Sites are located in Samish Bay, north, central, and south Hood Canal, Hammersley Inlet, and Willapa and Quilcene bays (Figure 5-23). These sites represent areas that were sources of two or more confirmed *V. parahaemolyticus* illnesses annually within the past three years.

Status and Trends

In 2006, a Washington record was set for the numbers of *Vibrio parahaemolyticus*-associated illnesses and laboratory confirmed cases of vibriosis was set. Among Washington residents and visitors to Washington who consumed local oysters during the outbreak, 113 cases of vibriosis were reported, with 71 of these cases being laboratory confirmed. The year-to-date total, which includes sporadic cases, is 124 cases, with 75 being laboratory confirmed. This reported outbreak surpasses that of 1997 and establishes a record that no one is anxious to soon exceed.

Figure 5-22. Domoic acid blooms in Puget Sound. The first major incursions of domic acid in Puget Sound occurred in 2003. The FDA domoic acid action level is 20 ppm. Above this level, shellfish are considered unsafe for human consumption.
(Source: DOH)

1 Littleneck clams - 36 ppm
Sept. 15, 2005

2 Blue mussel - 26 ppm
Sept. 19, 2005

3 Manila clams - 36 ppm
Pacific oysters - 30 ppm
Sept. 12, 2003

4 Blue mussel - 29 ppm
Sept. 2, 2003

5 Manila clams - 68 ppm
Blue mussel - 46 ppm

6 Dungeness crab - 28 ppm
Oct. 26, 2005

7 Manila clams - 32 ppm
Oct. 17, 2005

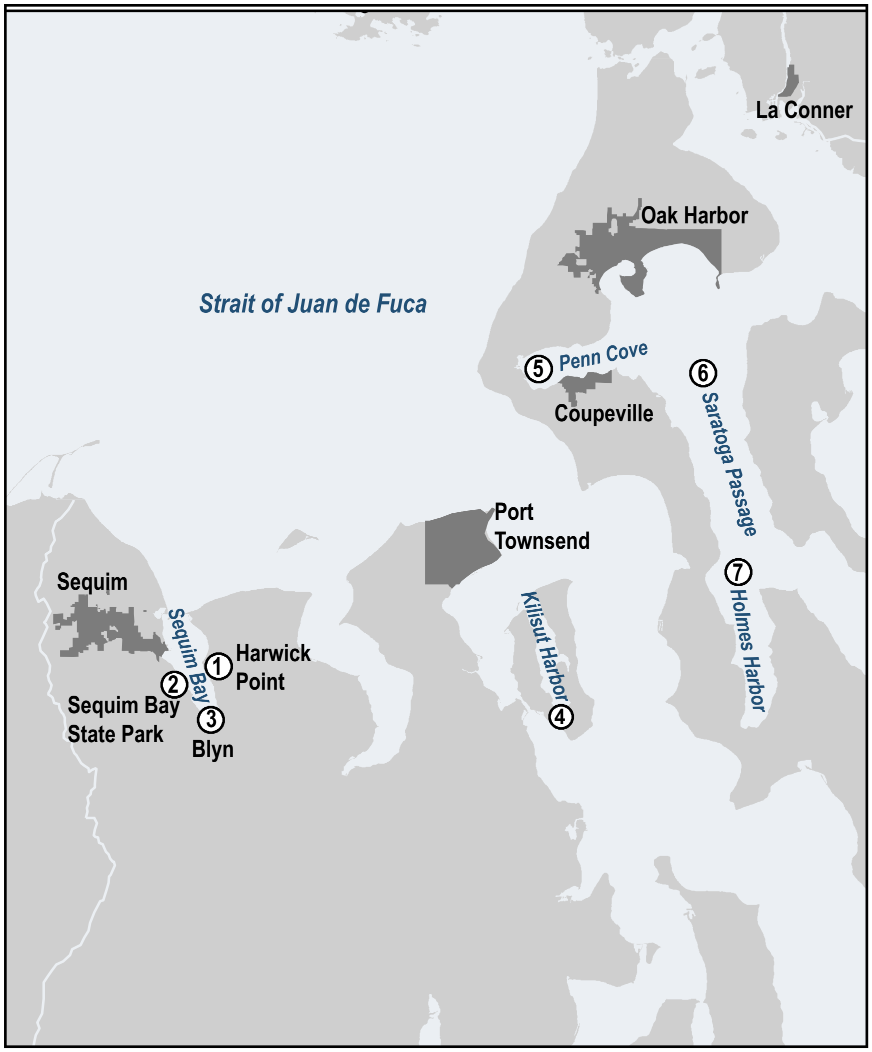
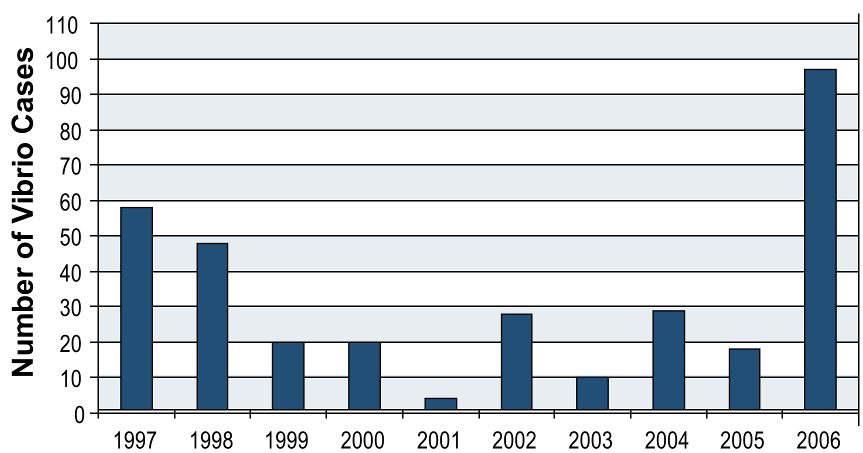


Figure 5-23. Vibriosis occurrence in Puget Sound. Confirmed cases of vibriosis from the disease's documented onset in Puget Sound in 1997 through 2006.
(Source: DOH)



8. State Controls

a. TMDL Process Overview

The federal Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the water bodies on the 303(d) list—the State's list of polluted water bodies. Also known as a water quality improvement project, a TMDL identifies how much pollution needs to be reduced from sources to achieve compliance with the state's water quality standards. Many of the water quality improvement projects are being conducted in the Puget Sound region to control and prevent pathogen and nutrient pollution. These include projects for the Skokomish, Nooksack, Union, Deschutes, Stillaguamish, and Dungeness rivers and numerous streams and other water bodies.

Ecology and other agencies provide technical expertise for the scientific analysis of each TMDL and related cleanup plans. Community residents have knowledge about their watersheds that helps to identify the pollution sources and the best management practices to fix the problems. Because solutions for water pollution problems require action on the parts of many people in a watershed, public participation in producing and implementing TMDLs is extremely important. By working together to produce the TMDL and identify solutions, local governments and citizens tend to take ownership of the plans and have stakes in their successful implementation to improve water quality within their communities.

b. 303(d) Listings in Puget Sound

Under the Clean Water Act, every state has its own water quality standards, designed to protect, restore, and preserve water quality. Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the 303(d) list or water quality assessment. To develop the list, Ecology compiles its own water quality data, along with data submitted by local, state, and federal governments, tribes, industries, and citizen-led monitoring groups. All data are reviewed to ensure that they were collected with appropriate scientific methods, before they are used to develop the 303(d) list.

There are currently 76 303(d) listings for fecal coliform contamination in Puget Sound marine waters (Figure 5-24).

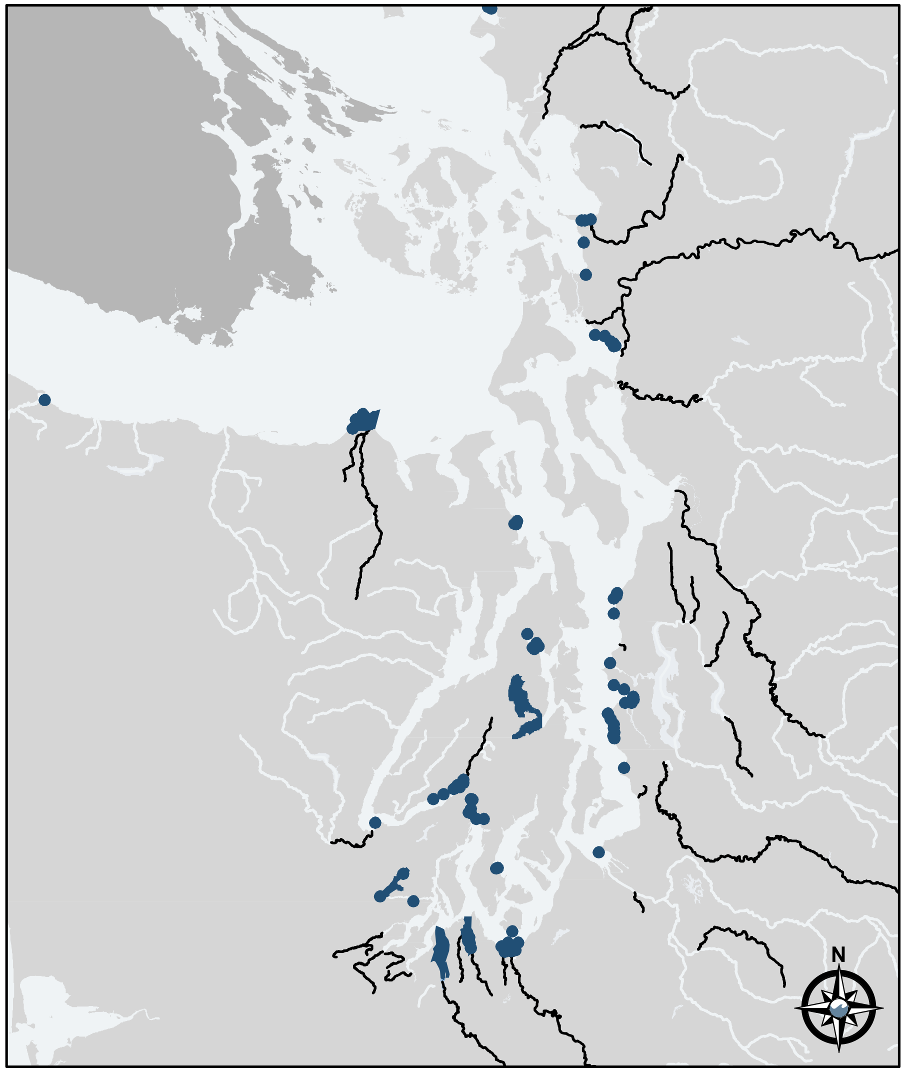
Within the 303d list, there are several categories of impairment:

- Category 1: Meets tested standards for clean waters.
- Category 2. Water of concern.
- Category 4: Polluted waters that do not require a TMDL:
  4a: Waterbodies that have an approved TMDL.
  4b: Water bodies that have a pollution control plan in place.
  4c: Water bodies that are impaired by a non-pollutant.
- Category 5: Polluted waters that require a TMDL.

In the 2004 Water Quality Assessment, 58 locations were identified in Puget Sound marine waters where low levels of DO are problems (Figure 5-25). Many other locations were deemed to be waters of concern. Excess nutrients (nitrogen, specifically) are a main cause of low DO levels, but also important are the low levels of nutrients in incoming oceanic water. Human sources of nitrogen come from both point sources and nonpoint sources. Outside of Hood Canal, the most significant, immediate DO issues are in the South Puget Sound Basin. Carr,

Figure 5-24. Locations of 303(d)-listed sites for fecal coliform contamination in Puget Sound. Most are located near urban areas, including Olympia, Seattle, Everett and Port Angeles. Hood Canal also has significant numbers of listed areas.
(Source: Ecology)

Fecal Coliform TMDLs
Listed Marine Area



Case, and Budd inlets are the locations of greatest concern. There are also DO problems in more localized areas of central and north Puget Sound (see Chapter 3, Section e).

Ecology and other agencies have been working on TMDLs to start addressing these problems. In the Puget Sound region, Ecology has started or completed TMDLs in 14 watersheds (Figure 5-26). Additional TMDLs will be needed to resolve some 303(d) listings that have not been addressed.

c. Point Sources and NPDES Permits

Under federal law, all states are required to address stormwater as a point source discharge. Phase I of the federal municipal stormwater program focused on large-sized municipalities. In 2000, Phase II of the federal municipal stormwater program imposed new requirements for smaller municipalities. There are now over 100 municipalities in Washington that require stormwater permit coverage under Phases I or II of the municipal National Pollutant Discharge Elimination System (NPDES) stormwater permit program. These municipalities vary in size, state of their existing stormwater programs, and funding abilities. This diversity makes development and implementation of stormwater permits challenging.

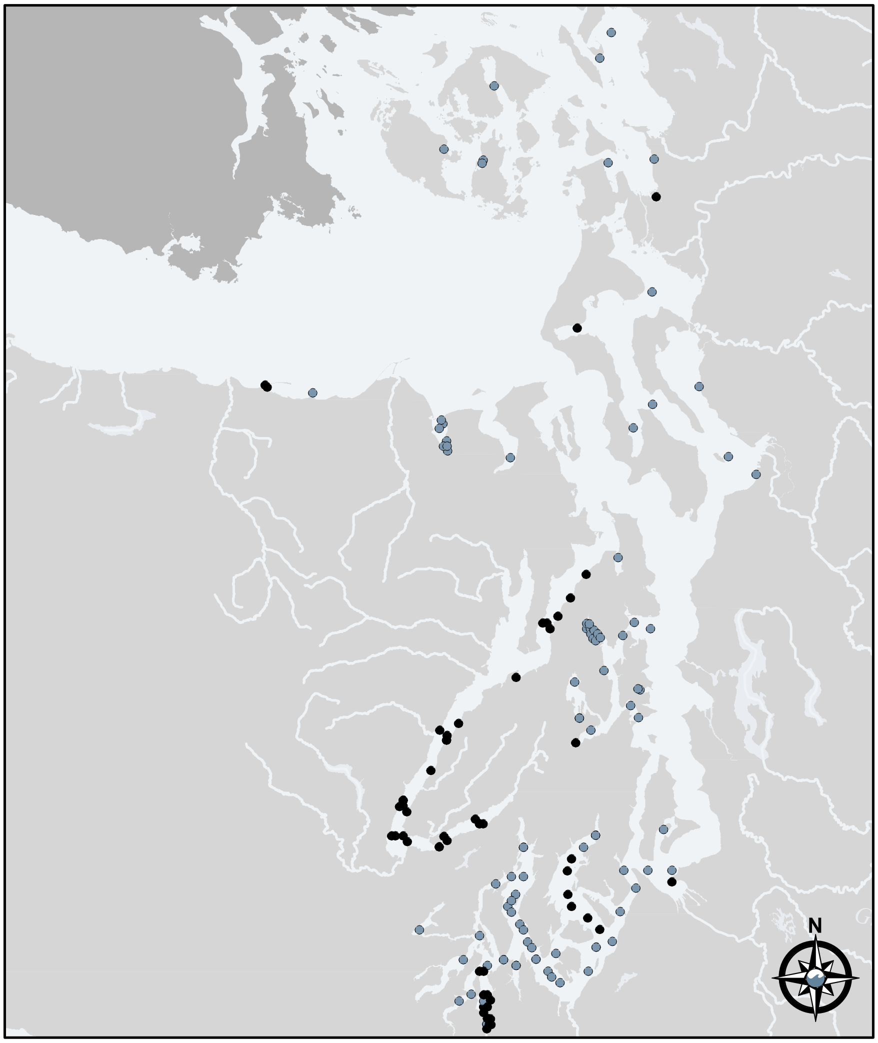


Figure 5-25. 303(d) listings for dissolved oxygen in Puget Sound. These data are from a variety of sources, including state, local, tribal, and citizen monitoring efforts. Most of the areas of highest DO concern are in Hood Canal and bays within central and south Puget Sound.
(Source: Ecology)

- Category 5: Impaired Water
- Category 2: Waters of Concern

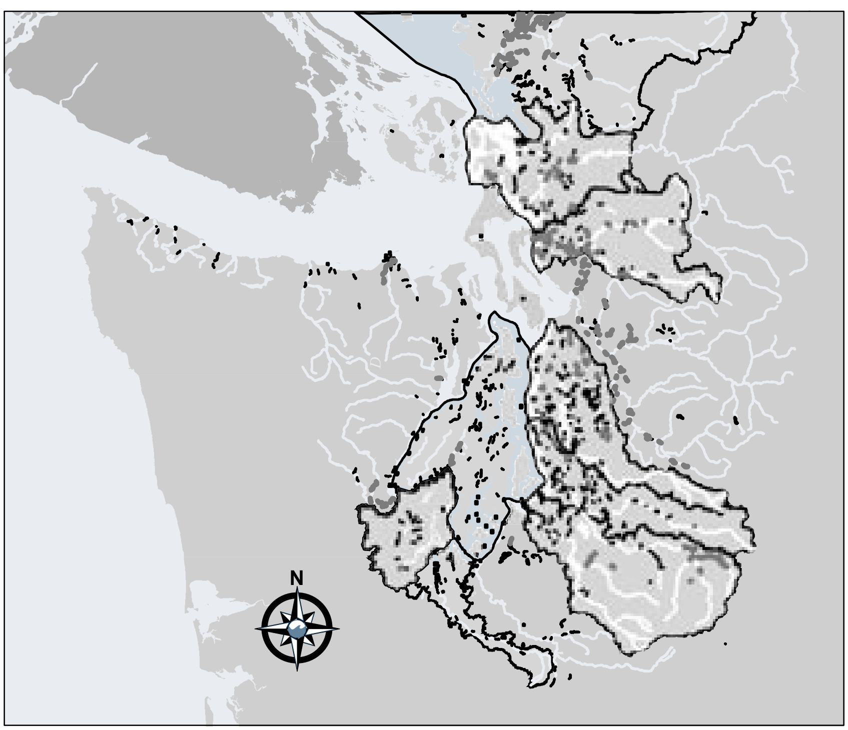


Figure 5-26. TMDLs and 303d listed fresh water and marine water bodies in Puget Sound. Every two years, Ecology assesses the quality of the surface waters of Washington state. Water bodies that do not meet the state's water quality standards because of human-caused problems are identified as "impaired" and assigned a category for further study and clean up. In 2004, there were approximately 1,474 listings of impaired waters in Puget Sound's fresh and marine waters. Most of the impairments are the result of toxic contamination, pathogens, low dissolved oxygen, and high temperatures.
(Source: Ecology)

- **Category 4A:** TMDL in place
- **303(d) List-Category 5:** Impaired waters
- Puget Sound WRIAs with TMDLs under development

9. New Approaches to Pathogen Control

a. Land Use Analysis

Efforts to protect and restore water quality in shellfish growing areas have generally focused on identifying and controlling pollution from individual sources, such as sewage treatment plants, failing onsite sewage systems, and livestock. This approach has been quite successful in the Puget Sound region, achieving a net upgrade of more than 8,000 commercial shellfish acres in the 11 years between 1995 and 2005. While these approaches must be maintained, there are a number of reasons why additional strategies should be pursued and efforts to more permanently safeguard the region's shellfish growing areas should be increased:

- The tenuous condition and classification of the restored shellfish areas and the need for ongoing attention.
- Relentless growth pressures in the region (population, development, land cover change).
- Increasing number of shellfish areas added to DOH's annual list of threatened shellfish areas.
- Increasing prevalence of stormwater impacts, making the pollution problems more complicated to assess and costly to correct.
- Greater understanding that many conventional pollution control practices do not fully mitigate impacts or fully protect the health and function of aquatic habitats.
- Better awareness that efforts and investments are often reactive and focused more on symptoms and short-term fixes than on underlying causes and lasting preservation.

Studies indicate that shellfish growing areas are vulnerable to contamination at relatively low levels of development, especially if watershed hydrologic processes are disrupted and there is high connectivity between the pollution sources and receiving waters. These impacts can worsen as population and development levels increases in the adjacent shorelines and watersheds. Contamination is not simply a function of the pollution sources; it is also a function of the landscape change. More development and modification of the landscape invariably increase the potential for contamination because of the efficient delivery of pollutants and the loss of native land cover and hydrologic features (e.g., wetlands) that effectively attenuate flows and contaminants.

Landscape analysis techniques have been used to assess the relationship between different landscape metrics (e.g., population density or percent land cover) and bacterial levels in commercial shellfish growing areas in the Puget Sound region. Research by Alberti and Bidwell (2005) examined relationships at the watershed and shoreline scale, using cross-sectional analyses (comparing different areas at the same point in time) and longitudinal analyses (comparing changes over time at different areas). The study concluded that different landscape patterns correlate strongly with bacterial levels in shellfish growing areas. (See Figure 5-27 in Appendix C: Color Figures.) Most notably, the researchers identified the amount and aggregation of forest cover as the best predictors of nearshore water quality (more forest cover correlated with lower bacterial levels) and also strongly correlated the amount and aggregation of impervious cover with water quality (more impervious cover correlated with higher bacterial levels).

10. Recommendations

In the *2002 Puget Sound Update*, recommendations were provided, based on the results from the studies reported. The recommendations for nutrients and pathogens work and progress made through 2006 on those recommendations are summarized below:

Recommendation from the *2002 Update* for Nutrients and Pathogens	Progress made through 2006 on recommendations in the *2002 Update*
Intensive and coordinated local efforts can reduce fecal pollution problems as evidenced by successes in the Nooksack basin and seen in previous results for Eld Inlet and Oakland Bay, presented in the *2000 Puget Sound Update*.	• Skagit County Health Department created an Area of Special Concern for the Dewey Beach area of Fidalgo Island and mandated regular inspection of onsite sewage systems. • Thurston County Health Department created the Henderson Inlet Shellfish Protection District and mandated regular inspection of onsite sewage systems. • Kitsap County Health District sampled shoreline seeps along a portion of the Hood Canal, identified malfunctioning onsite systems and worked with owners to obtain repairs.
Such efforts should be initiated at all areas where DOH's analysis indicates worsening trend, especially those areas where currently open shellfish harvest areas would be threatened with downgrades if the trend were to continue. These include Henderson Inlet, Dungeness Bay, and south Skagit Bay.	See above.
Wherever possible, monitoring should adopt an interdisciplinary approach that integrates sampling of pathogens and nutrients with physical parameters of the receiving water body and the nature of the sources. Areas of Puget Sound that are sensitive to nutrient-related water quality degradation should be investigated further to characterize nutrient loading and cycling.	• The Hood Canal Dissolved Oxygen Program established a coordinated monitoring effort to characterize water quality in the Hood Canal and determine the sources, transport, and fate of nitrogen. • Ecology has routinely sampled nutrients, fecal coliform bacteria and physical parameters at its long-term marine monitoring stations since 1973. These data are also collected during most other marine monitoring activities.
Decisions about the discharge of nutrients to Puget Sound from point and non-point sources should incorporate an understanding of the local marine area's sensitivity to nutrient-related water quality degradation. Areas of Puget Sound shown to be sensitivity to eutrophication would be managed accordingly.	• Onsite sewage treatment devices were installed at Hood Canal sites by the Puget Sound Action Team and are being monitored to characterize nitrogen removal. • The Legislature funded research being conducted by the University of Washington to study the movement of nitrogen from onsite sewage systems into Hood Canal marine waters. • Ecology recently received funding to collect data needed to determine how much nitrogen from a variety of sources affects DO levels in South Puget Sound. This supports Ecology's efforts to continue development of an existing South Sound model as a tool for identifying the impacts of increased nutrient loading.

Moving Forward on Puget Sound Science

In looking ahead to what recommendations to report on in future editions of the *Puget Sound Update,* it makes sense to focus on the goals and strategies that have been recommended in *2006 The Puget Sound Partnership Final Report*, the PSAT *2007-2009 Conservation and Recovery Plan for Puget Sound* and the 2006 PSAMP Review. Collectively, these three sources provide targets and goals developed and supported by a large scientific community and reflect both short-term (two year) and long-term considerations for protecting and restoring Puget Sound's health.

The following bullets summarize the goals and strategies put forth in by the Puget Sound Partnership, PSAT and PSAMP that are related to nutrients and pathogens (Chapter 5 of this report). Progress towards these goals and strategies will be reviewed in the next edition of the *Puget Sound Update*.

Puget Sound Partnership Final Report (from Appendix A):

Goal: Puget Sound marine and fresh waters are clean

- Toxics and pathogen levels in marine mammals, fish, birds, shellfish, and plants do not harm the persistence and health of these species.
- Loadings of toxics, nutrients and pathogens do not exceed levels consistent with health ecosystem functions.
- The waters in Puget Sound region are safe for drinking, swimming, and other human uses and enjoyment.

2007-2009 Conservation and Recovery Plan for Puget Sound

Priority 4. Reduce nutrient and pathogen pollution

- Focus efforts and resources in high-risk areas most vulnerable to the effects of pathogen and nutrient pollution.
- Enhance state agency coordination and implementation of programs and projects.
- Support effective and innovative implementation of regulatory and non-regulatory approaches.
- Enhance the capacity of local jurisdictions to design and implement effective and comprehensive programs using a range of regulatory and non-regulatory approaches.
- Educate and involve residents and others to enhance stewardship activities.
- Enhance monitoring, modeling and other assessment activities to better understand the pollution problems and guide management activities.

The Role of Science

Strategies:

- Continue ongoing monitoring of the status and trends of key components of the Puget Sound ecosystem.
- Provide scientific information to stakeholders, decision-makers and the public.
- Direct new monitoring activities to focus on the effectiveness of management activities and policy initiatives.
- Develop a roadmap to prioritize, finance, and conduct focused research on emerging topics or research questions that are brought forth through PSAMP and science programs.

Detailed recommendations for further research and monitoring

Many of the following recommendations are an outcome of the 2005-2006 PSAMP review and have been included as recommended actions in the *2007-2009 Puget Sound Conservation and Recovery Plan*. Progress towards these and previous recommendations will be reported in the next edition of the *Puget Sound Update*.

Water quality and biota assessment

- Assess the factors causing the intermittent production of domoic acid.
- Monitor water quality including nutrients and DO levels in the Strait of Juan de Fuca, the source of marine water for greater Puget Sound, including Hood Canal.
- Monitor PSP with sentinel mussel program to protect human health.
- Enhance monitoring of pathogens in swimming areas.
- Take steps toward developing a comprehensive assessment of nutrient inputs to Puget Sound and identify priority geographical areas and strategies to prevent and control those inputs.

Modeling

- Build and populate models for the transport and fate of nutrients in the Puget Sound ecosystem, based on the Puget Sound conceptual model.